

OXIDATION IN SOILS, AND ITS CONNEXION WITH FERTILITY.

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INTRODUCTION.

THE phenomena attending the absorption of oxygen by soils have been investigated by Déherain and Demoussy, and also by Wollny. An account of the work of the French chemists can be found in the *Annales Agronomiques*¹. Their method was to place the soils under examination in a closed tube holding about 100 c.c. and kept at constant temperature, then after a certain time to extract the gases and determine the carbon dioxide present. This was taken to be a measure of the amount of oxidation. The general results they obtained are as follows:

1. The quantity of carbon dioxide produced increases with the temperature to about 65° C., and then decreases. At higher temperatures (above 90°) it increases again.

2. It increases with the amount of water present up to a certain point, and then decreases. This optimum amount, however, varies from soil to soil.

3. It is greatly influenced by the state of division of the soil. Déherain and Demoussy recognise that the production of carbon dioxide only partially represents what the oxygen has done, but the results obtained in different experiments are considered to be comparable.

Wollny² independently investigated the problem somewhat more fully. His method was essentially the same; 100 gms. of soil were kept at constant temperature, and the carbon dioxide produced was estimated.

¹ *Ann. Agron.* Vol. xxii. p. 305.

² *Die Zersetzung der organischen Stoffe*, 1897.

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He obtained the results set out above, and the following additional ones:—

4. Oxidation is checked or altogether inhibited in presence of antiseptics.

5. It is increased by adding lime, and also, in some cases, by adding culture solutions.

The deduction was drawn that oxidation is mainly, if not entirely, bacterial.

The method is open to much criticism and to some serious objections. The implied assumption that the evolution of carbon dioxide is proportional to the amount of oxygen absorbed is nowhere proved; the presence of the carbon dioxide formed may reasonably be supposed to interfere with oxidation, and, further, the extraordinary power some soils possess of absorbing carbon dioxide introduces errors. Moreover the experiments are by no means easy to carry out, and it is probably for this reason that the rate of oxidation has so far found no practical application.

METHOD OF INVESTIGATION.

Instead of determining the carbon dioxide produced, the author has measured the actual amount of oxygen taken up. The apparatus, which is extremely easy to make, consists of a flask of about 100 c.c. capacity with two tubes sealed into its neck. The wider of these (*A*, Fig. 1) is bent at right angles and terminates in a bulb *B*; higher up is the narrower one, *C*, of about 4 mm. diameter, also bent at right angles, but open at the end. A weighed quantity of the air-dried soil is introduced into the flask, a definite amount of water is added, and the neck of the flask is either sealed up or closed with a very well-fitting rubber cork. Potash solution ($1 \text{ KOH} : 2\text{H}_2\text{O}$) is run into *B* by the little side tube *D*, which is then sealed, and the end of *C* is dipped under mercury, thus converting it into a gauge. The apparatus is now placed in a water-bath at constant temperature, oxygen is absorbed, and doubtless a complex reaction takes place, but the only gas likely to be set free from ordinary soils is carbon dioxide, and this is so rapidly absorbed by the potash that at any given moment the quantity present in the free state is negligible.

The absorption of oxygen is indicated by the rise of mercury in *C*, and from a measurement of the height of the column above the surface the amount of oxygen taken up is readily found. A cathetometer and millimetre scale are used for this purpose. In practice six or seven

soils can very well be examined simultaneously, the experimental vessels are made of approximately the same size, they are numbered and calibrated, and the potash solution run into *B* is in such quantity that the volume of air left is the same in all the vessels. They are then fixed in a curved water-bath, so that all the gauges are in focus simultaneously.

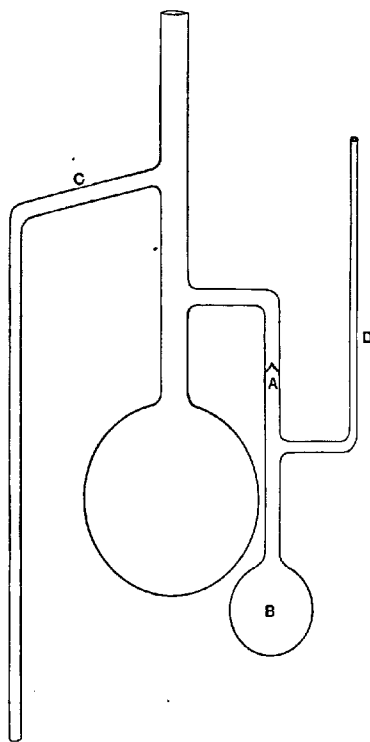


FIG. 1.

The disposition of the apparatus is shown in Fig. 2. Readings are facilitated if at the outset the bulb *B* is slightly warmed to expel some of the contained air, the mercury column then starts well above the surface, and a sudden drop in the barometer does not have the effect of depressing the mercury to a point where it could not be read.

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Absorption is slow, lasting some days or even weeks, and in order to obviate difficulties attending changes of temperature and pressure it is necessary to have in the bath a control apparatus containing no soil.

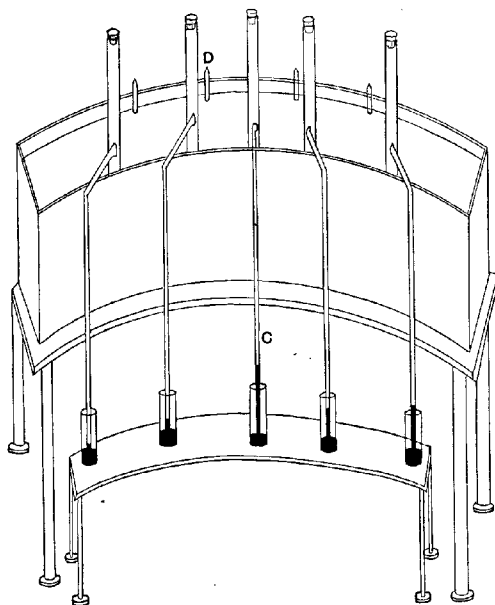


FIG. 2.

The movements of mercury in this case depend entirely on changes of temperature and pressure and give a correction which is readily applied to the other vessels. The method of reducing the readings will be seen from the following example:—

Control Flask.

| | Height of mercury above surface | Change produced by alteration in temperature and pressure since beginning |
|-------------|------------------------------------|---|
| Jan. 25 ... | 83.4 mm. | |
| Feb. 2 ... | 79.9 " | - 9.5 |
| " 14 ... | 88.9 " | + 5.5 |

Soil No. 1 in Flask 1.

| | | | |
|------------------------------|----------|------------------------------|------------|
| Weight of air-dried soil ... | 10 grams | Total volume of apparatus... | 107.5 c.c. |
| Water added..... | 2 c.c. | Potash run into B | 11.0 c.c. |
| | | Volume of air and soil | 96.5 c.c. |

| | Height of mercury above surface | Corrected for change of temperature and pressure | Actual absorption of oxygen |
|-------------|------------------------------------|---|--------------------------------|
| Jan. 25 ... | 50.5 mm. | | |
| Feb. 2 ... | 57.3 " | 66.8 mm. | 16.3 mm. |
| " 14 ... | 83.7 " | 78.2 " | 27.7 " |

Soil No. 2 in Flask 2.

| | | | |
|------------------------------|----------|------------------------------|------------|
| Weight of air-dried soil ... | 10 grams | Total volume of apparatus... | 104.7 c.c. |
| Water added..... | 2 c.c. | Potash run into B | 8.2 c.c. |
| | | Volume of air and soil | 96.5 c.c. |

| | Height of mercury above surface | Corrected for change of temperature and pressure | Actual absorption of oxygen |
|-------------|------------------------------------|---|--------------------------------|
| Jan. 25 ... | 28.3 mm. | | |
| Feb. 2 ... | 29.3 " | 38.8 mm. | 10.5 mm. |
| " 14 ... | 55.1 " | 49.7 " | 21.4 " |

The experiment actually began on Jan. 24th, but the apparatus was left for 24 hours to ensure it taking the temperature of the bath. The corrected value on Feb. 2nd is obviously obtained by adding 9.5 and on Feb. 14th by deducting 5.5. The absolute weight of oxygen absorbed can of course be readily calculated from the diminution of oxygen pressure recorded in the third column, but for our present purpose there is no advantage in doing this; the experiments are all carried out under comparable conditions and the figures are used as they stand.

Preparation of the soil. The samples, taken with the usual precautions, are spread out on trays to dry sufficiently to allow them to be pulverised and sifted. The drying should not go too far, and the same sized sieve must be used in all experiments. For accurate work the sifted samples must be kept over water for 24 hours, but for ordinary purposes this is not necessary. In all the experiments recorded here 10 grams of air-dried soil were used, and for a given set of experiments the amounts of distilled water added were constant.

The temperature in all cases was about 17° C.

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INFLUENCE OF VARIOUS FACTORS ON THE RATE OF OXIDATION.

1. The quantity of soil taken.

| Quantity of soil | Oxygen absorbed in | |
|------------------|--------------------|----------|
| Loam, Rothamsted | 7 days | 48 days |
| 5 grams..... | 1.73 mm. | 8.81 mm. |
| 10 " | 2.41 " | 12.60 " |

| Quantity of soil | Oxygen absorbed in | | |
|------------------|--------------------|----------|-----------|
| Chalky loam, Wye | 6 days | 27 days | 40 days |
| 5 grams..... | 5.6 mm. | 13.6 mm. | 20.53 mm. |
| 10 " | 8.53 " | 22.6 " | 30.04 " |

Oxidation is not proportional to the weight of the soil, but more probably is related to the extent of the surface.

2. Amount of water present. (a) A fairly stiff loam was used.

| | Oxygen absorbed in | |
|---|--------------------|------------|
| | 7 days | 48 days |
| Air-dried soil, containing 6.33 % "hygroscopic" water ... | <i>nil</i> | <i>nil</i> |
| The same soil, containing 10 % added water | 1.73 mm. | 8.81 mm. |

(b) Chalky soil, Wye.

| | Oxygen absorbed in 23 days |
|--|----------------------------|
| Air-dried, containing 7.4 "hygroscopic" water..... | 6.5 mm. |
| 20 % added water | 21.6 " |
| 25 % added water | 27.7 " |

A preliminary trial is always necessary in adding water because some soils show a critical point beyond which a small addition of water causes the whole to form a sticky mass.

| Added water | Oxygen absorbed in | |
|---------------------------------------|-------------------------|------------------|
| | 8 days | following 6 days |
| 20 %, soil still loose | 9.94 mm. | 10.25 mm. |
| 21 %, sticky mass just forming | 5.28 " | 9.05 " |
| 21.5 %, sticky mass completely formed | slight evolution of gas | 9.00 " |

After the first abnormal period oxidation proceeds regularly enough, but this particular quantity of water is to be avoided.

3. Influence of lime and calcium carbonate.

| | Oxygen absorbed in | |
|------------------------|--------------------|-------------------|
| | 8 days | following 21 days |
| Sandy soil alone | 2.40 mm. | 3.47 mm. |
| „ + 3 % CaO... | 1.46 „ | 5.00 „ |

The addition of lime at first delays oxidation, but after a time it is converted into the carbonate, and oxidation is accelerated.

| | Oxygen absorbed in | |
|---------------------------------|--------------------|------------|
| | 4 days | 31 days |
| Fertile alluvial soil | 28.21 mm. | 109.07 mm. |
| „ + 1 % CaCO ₃ | 29.61 „ | 124.33 „ |
| „ + 2 % CaCO ₃ | 30.27 „ | 131.39 „ |

4. Surface soil compared with the subsoil.

Deep alluvial soils, situated on Romney Marsh.

| | Oxygen absorbed in | |
|---|--------------------|-----------|
| | 7 days | 28 days |
| No. 1. Surface soil (0—6") | 26.27 mm. | 61.73 mm. |
| Subsoil (6"—12") | 19.4 „ | 38.53 „ |
| No. 2. Surface soil (0—6") | 13.21 „ | 37.94 „ |
| Subsoil (6"—12") | 8.0 „ | 21.6 „ |
| Light sandy soil. Surface soil (0—6") ... | 2.92 „ | 8.66 „ |
| Subsoil (6"—12") | 1.59 „ | 1.86 „ |

Rothamsted soil. Samples from fallow piece in Little Hoos field.

| | |
|-----------------------------|-----------|
| Taken at 10 cm. depth | 15.00 mm. |
| „ 20 „ | 13.07 „ |
| „ 30 „ | nil |

The conditions obtaining in the subsoil are evidently not favourable to oxidation even when there is an ample supply of oxygen. This may probably be connected with the smaller amount of organic matter in the subsoil and its more resistant character as compared with that in the surface soil.

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5. Influence of sterilisation.

| | Oxygen absorbed in 10 days |
|--------------------------------------|----------------------------|
| Fertile loam | 27.19 mm. |
| „ heated for 30 minutes at 130°..... | 8.19 „ |
| „ + 1 % mercuric chloride..... | 7.18 „ |

Oxidation is not inhibited, but is greatly reduced, by these processes.

It is possible to stimulate oxidation, but this question, and others dealing more fully with the mechanism of the process, will be reserved for a future communication.

6. Age of the sample. Chalk-loam, Wye.

| | Oxygen absorbed in | | |
|--|--------------------|-----------|-----------|
| | 6 days | 27 days | 40 days |
| Sample taken Jan. 23rd, and kept till May in air-dried condition | 7.06 mm. | 22.60 mm. | 30.40 mm. |
| Sample taken May 10th, air-dried and used at once..... | 8.53 „ | 22.60 „ | 30.04 „ |

The sample showed no deterioration when well preserved for three and a half months.

FERTILITY AND THE RATE OF OXIDATION.

From the results set out above it is evident that the same factors which increase the productiveness of the soil—temperature, water, calcium carbonate, etc.—also increase the rate of oxidation, whilst those inimical to the one—sterilisation, and the general conditions obtaining in the subsoil—also decrease the other. If both are influenced to somewhat the same extent by these different factors, then the rate of oxidation should afford a valuable indication of the relative fertility of different soils.

A number of soils of known fertility have been examined. In each series the investigation has been confined to soils of the same type from similarly situated and closely adjacent fields. Only in this way can the disturbing effect of climate and the physical structure of the soil be eliminated.

ARABLE SOILS.

1. Soils of equal fertility from the same field.

The samples were taken from a level field on the College farm (chalky loam) known from its crop yields to be fairly uniform.

| | Oxidation in 22 days |
|---------------|----------------------|
| Sample 1..... | 22.60 mm. |
| " 1..... | 21.86 " |
| " 2..... | 21.5 " |

2. Soils of different fertility.

A. *Sandy Soil.*

(a) Samples from the Woburn Experimental Station (Lower greensand formation) were very kindly prepared for me by Mr S. F. Ashby, to whom I am greatly indebted also for the Rothamsted samples used in another series of experiments.

| Sample No. | Name of Field | History | Average of last 4 crops (bushels) | Oxidation in 17 days (mm.) |
|------------|-------------------|--|-----------------------------------|----------------------------|
| 7 | Stiff Oxford Clay | Wheat stubble | — | 23.2 |
| 2 | Road piece..... | After wheat, preceded by mangolds, fed with cake or corn | — | 18.7 |
| 5 | Lansome Field... | Barley 1904 after wheat 1903 and mustard ploughed in (1902), mineral manure... | 26.5 | 14.1 |
| 6 | " | Barley after wheat and tares ploughed in (1902), mineral manure | 17.2 | 10.2 |
| 4 | " | Barley after wheat and tares ploughed in (1902), no mineral manure | 16.1 | 8.2 |
| 8 | Stackyard Field.. | Continuous wheat, unmanured | 9.2 | 8.2 |
| 9 | " | Continuous wheat, ammonium salts containing 50 lbs. ammonia only | 6.3 | 7.8 |

In a letter to me on the fertility of these plots, Dr Voelcker, who has kindly taken the greatest interest in these determinations, says:—"No. 7, stiff Oxford clay is undoubtedly the richest soil of the number. I should certainly call Road piece (No. 2) the second best of the series. As between Lansome Field Nos. 5, 6, 4, and Stackyard Field, Nos. 8 and 9, there is, I should say, not a great difference as regards inherent fertility, but, taking the samples selected, the individual ones from Lansome are, no doubt, at present more fertile than the selected ones from Stackyard Field."

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Turning now to the oxidation results, the order in each of the groups is the same as for the fertility; the same order appears, too, when the groups are compared with one another. The great fall in the crop on Stackyard Field is probably rather due to secondary causes than to deficiencies in the soil.

(b) Sandy Soil from Bramley, Surrey.

In a large fruit plantation (chiefly gooseberries) owned by Messrs E. Ellis and Son, there was a portion decidedly less productive than the rest, although the manuring and cultivation had been in all respects the same.

The amounts of oxidation after 8 days were:

| | Fertile portion (a) | Less fertile portion (b) |
|--------------------|---------------------|--------------------------|
| Surface soil | 2.92 mm. | 2.40 mm. |
| Subsoil | 1.59 " | .40 " |

At the end of four weeks the differences were more accentuated:

| | Fertile portion (a) | Less fertile portion (b) |
|--------------------|---------------------|--------------------------|
| Surface soil | 8.66 mm. | 5.87 mm. |
| Subsoil | 1.86 " | nil |

The poorness of (b) is therefore due in part at any rate to some fault inherent in the soil itself and not merely to its situation or water supply, the subsoil in particular being apparently absolutely sterile. An obvious advantage of the method is that it enables one to localise the trouble.

B. Loams.

With the kind permission of Mr A. D. Hall samples were obtained from Rothamsted.

Agdell Field, Rotation experiment.

| No. | | Manuring | Oxidation in | |
|----------------|---|---------------------|--------------|---------|
| | | | 4 days | 6 weeks |
| | | | mm. | mm. |
| A ₃ | Roots fed on ground: beans or clover... | minerals + nitrogen | 3.86 | 15.40 |
| A ₂ | " " " " ... | minerals | 2.66 | 11.63 |
| A ₁ | " " " " ... | no manure | 2.27 | 9.00 |

Reference to the Rothamsted memoranda shows that this is also the order of productiveness.

Broadbalk Wheat Field.

| Plot | Manuring | Average crop | Oxidation in | |
|------|---|--------------|--------------|-----------|
| | | bushels | 7 days | 6 weeks |
| 2 B | Farmyard manure, 14 tons | 35.6 | 6.93 mm. | 37.74 mm. |
| 19 | Rape cake containing 92.6 lbs. nitrogen | 26.7 | 8.74 „ | 12.73 „ |

Barnfield Mangold plots.

| Plot | Manuring | Average crop | Oxidation in | | |
|----------|-----------------------------|--------------|--------------|-----------|-----------|
| Series 5 | | tons | 8 days | 14 days | 6 weeks |
| Plot 1 | Farmyard manure + rape cake | 24.12 | 9.94 mm. | 20.19 mm. | 41.69 mm. |
| „ 4 | Minerals + rape cake | 21.39 | 7.27 „ | 16.00 „ | |

In all cases the indications given by this method completely accord with the crop yields.

C. Chalk Soils.

These were taken at Wye and included samples from:—

(1) An old pasture land now broken up and put into oats (Marriage Farm).

(2) The College hop garden, which receives each autumn about 20 loads of dung to the acre.

(3) A very similar plot, which received the same quantity of dung last autumn preparatory to a mangold crop, but is not generally as well treated as (2).

(4) A poorer plot, barley stubble, previous to which roots had been folded off.

| | Oxygen absorbed in | | |
|------------------------|--------------------|----------|-----------|
| | 6 days | 27 days | 40 days |
| 1. Old pasture..... | 18.07 mm. | 51.4 mm. | 64.04 mm. |
| 2. Hop garden..... | 8.66 „ | 24.13 „ | 32.40 „ |
| 3. Mangold plot | 8.53 „ | 22.6 „ | 30.04 „ |
| 4. Barley stubble..... | 7.26 „ | 21.46 „ | 29.53 „ |

As a result of some years' experience with the College soils, Mr K. J. J. Mackenzie, the lecturer on Agriculture, considers that the differences between 2, 3, and 4, are probably not great, but that they

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should be placed in the above order. 4 is thinner than 3, and therefore dries out more readily, causing the difference in yield.

The fertility of the old pasture soil cannot yet be gauged, but it seems remarkable that the rate of oxidation should come out so much higher than the others, which have been arable land for many years.

The order in which the soils appear, and the differences between the observed rates, fit in with what is known of their productiveness.

PASTURE SOILS.

In some cases the method has worked satisfactorily, but in others it has failed. There is considerable difficulty in deciding whether the pooriness of a pasture is due to bad management allowing weeds to crowd out the grasses, and also it is quite possible that the conditions of fertility in arable and pasture fields are not identical.

I. Gault Pastures, Cambridge.

Professor T. H. Middleton kindly sent me three pasture soils arranged in the following order:

1. Old pasture ploughed up three months earlier. Small paddock closely grazed by cattle.
2. Pasture on the University Farm.
3. Very poor old grass field, which has probably been neglected.

Professor Middleton added that he had not himself seen No. 3.

| | Oxygen absorbed in | | | |
|-------------------------|--------------------|-----------|-----------|-----------|
| | 2 days | 4 days | 10 days | 38 days |
| No. 1. Good..... | 4.67 mm. | 11.26 mm. | 27.19 mm. | 57.37 mm. |
| No. 2. Poorer | 3.0 „ | 7.45 „ | 17.45 „ | 37.03 „ |
| No. 3. Reported poor... | 6.8 „ | 12.06 „ | 24.66 „ | 56.43 „ |

At a later date Professor Middleton wrote saying that he had been to field No. 3 and considered the soil certainly better than No. 2. He placed the order of fertility so far as the soils were concerned as

No. 1,

No. 3,

No. 2,

which corresponds with the order of oxidation.

No. 3 shows a curious change in its behaviour, oxidising first more rapidly, afterwards more slowly than No. 1.

II. Alluvial Pastures, Romney Marsh.

Soils were taken from Orgarswick, the farm of H. J. Clements, Esq.

1. "Fatting Field" carries and fattens 6 sheep per acre in summer and $2\frac{1}{2}$ in winter. It is too strong for lambs.

2. "Jeffry's 10 acre Field" is not as good, but had been mis-managed before Mr Clements took it.

3. "Fresh Field" was arable till 5 years ago, yielding 7 or 8 quarters of wheat, 14 of oats, and 7 of beans. It was laid down to permanent pasture by Mr Clements' predecessor, but an unsuitable mixture was used, and the appearance of the field is now pitiable, when one thinks of its past history.

4. "Middle Field." The poorest of the lot. It carries 4 sheep with lambs in summer, and 2 in winter, but it does not fatten them.

These fields all adjoin one another, and there is no way of accounting for the marked difference between Nos. 1 and 4. Similar cases, however, occur not infrequently in Romney Marsh.

| | Oxygen absorbed in | | | |
|-----------------------------|--------------------|-----------|-----------|------------|
| | 4 days | 6 days | 20 days | 31 days |
| No. 1. Fatting Field ... | 18.35 mm. | 27.75 mm. | 69.00 mm. | 102.27 mm. |
| No. 2. Jeffry's 10 acre ... | 26.07 " | 39.87 " | 79.47 " | 98.46 " |
| No. 3. Fresh Field | 13.48 " | 17.55 " | 38.2 " | 53.08 " |
| No. 4. Middle Field ... | 28.21 " | 43.54 " | 95.13 " | 109.07 " |

No. 4 is abnormal throughout, Nos. 1 and 2 show the same peculiarity as in the gault soils. On the 31st day Nos. 1, 2, and 3, come out in their proper order, but No. 4 is altogether in the wrong place, and on the earlier days No. 2 is also in the wrong place.

At present I do not consider the method is suitable for pasture land; it appears, however, to give useful results for arable land. In the foregoing pages I have included every reading with every soil examined; it will be seen that the result invariably accords with the history of the soil, excepting in the pasture soils.

DISCUSSION OF THE METHOD.

Signification of the results. The rate of oxidation depends on all the factors influencing the fertility of the soil, but the relationship is complex, and in a given series of soils these factors interact to so great an extent that it is not as a rule possible to directly connect the oxidation results with any one of them. This is well seen in the Woburn

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soils; determinations of the carbon, nitrogen, and calcium carbonate were made and are set out below. The soils are arranged in their order of oxidation, but neither of these shows any simple connexion with the other factors.

| Order of fertility and oxidation (see page 269) | Nitrogen | Carbon | Ratio C : N | Loss on Ignition | "Hygroscopic water," (i.e. lost at 95° but not at 15°) | Calcium carbonate |
|--|----------|--------|----------------|---------------------|---|----------------------|
| 7 | ·2520 | 2·534 | 10·06 | 8·73 | 4·12 | ·0206 |
| 2 | ·1724 | 1·765 | 10·24 | 5·31 | 1·60 | ·0720 |
| 5 | ·1217 | 1·193 | 9·80 | 4·17 | ·976 | ·027 |
| 6 | ·1322 | 1·242 | 9·32 | 3·22 | 1·16 | ·051 |
| 4 | ·1094 | 1·181 | 10·81 | 3·46 | 1·04 | ·0084 |
| 8 | ·0604 | 1·389 | 23·0 | 4·07 | 1·16 | ·0042 |
| 9* | ·1022 | 1·290 | 12·62 | 4·58 | 1·18 | nil |

* It was discovered afterwards that the sample of No. 9 sent for analysis came from the *barley* plot, whilst that previously investigated was from the *wheat* plot. The two are in the same field, not 50 yards apart, similarly situated and with the same manurial and crop history. It is reasonable to suppose that the analytical data would be much the same in both.

The percentages are calculated on the air-dried soil.

Organic Matter. It is impossible to estimate the precise amount of organic matter in the soil, it is usually taken as being proportional either to the loss on ignition or to the quantity of carbon present, but the two methods do not lead to the same result. Placing the soils in descending order we get

- (1) from loss on ignition 7 2 9 5 8 4 6,
- (2) from carbon determinations 7 2 8 9 6 5 4,
- order of oxidation 7 2 5 6 4 8 9.

No. 8 contains so little nitrogen that the percentage of carbon in its organic matter must be unduly high, and hence a false position is assigned. No. 6, which was green manured with tarcs, contains more carbon and also more nitrogen than No. 5, where mustard was ploughed in; but if the loss on ignition figures have any value they indicate that No. 5 contains more organic matter than No. 6. If the extra hydrogen and oxygen in No. 5 denote a further stage in the hydrolysis of the organic matter, we should have an explanation of the higher rate of oxidation of No. 5 than of No. 6. But the ignition figures have to be interpreted with great caution, and deductions must not be carried too far. Dr Voelcker in his Report for 1902 has called attention to the special interest attached to these two plots.

The high position of No. 9 in both lists is easy to understand, excessive ammoniacal manuring has made the soil acid to litmus paper and largely sterile to bacteria. Barley fails, but spurry flourishes, and, as oxidation is not vigorous, organic matter tends to accumulate.

Thus although the values obtained and the order assigned in the above list may be reconciled with one another and with the history of the plots, they would not enable useful deductions to be drawn as to the productiveness of the plots.

It is quite evident that the rate of oxidation is not proportional to the amount of organic matter present.

Nitrogen. Arranging as before in descending order of magnitude we get 7 2 6 5 4 9 8,
whilst the order of fertility is 7 2 5 6 4 8 9.

The order in both cases agrees fairly closely. Nos. 5 and 6 are transposed, and the analyst would in all probability fall into error over these two. No. 9 also appears in its wrong place, but the acid reaction of the soil and its manurial history would prevent any mistake being made as to its fertility. It is indeed remarkable that No. 9 does not contain more nitrogen considering the small crops grown and the large amount of ammonia annually supplied. Even on the stiffer soil at Rothamsted, however, it is not found that ammonia persists for any length of time, still less would it be likely to accumulate on the light Woburn soil.

It would not be justifiable to conclude that the rate of oxidation is proportional to the amount of nitrogen present, for the above exceptions are of very real significance. More probably nitrogen is one of the predominant factors determining the fertility of these particular soils, and if that is so, one would expect it to show a certain parallelism with the rate of oxidation. But the two are fundamentally distinct, and the present agreement is purely accidental.

Ratio of Carbon to Nitrogen, and vice versâ. The order of magnitude is:

| | | | | | | | |
|---------------------------------|---|---|---|---|---|---|----|
| ratio <i>C</i> : <i>N</i> | 8 | 9 | 4 | 2 | 7 | 5 | 6, |
| ratio <i>N</i> : <i>C</i> | 6 | 5 | 7 | 2 | 4 | 9 | 8, |
| rate of oxidation | 7 | 2 | 5 | 6 | 4 | 8 | 9. |

At first sight a greater agreement might have been expected. The losses during decay fall more on the carbon than on the nitrogen, and a decrease in the ratio *C* : *N* might be anticipated. Thus a high ratio would indicate fresh organic matter, and a low ratio the residual, and

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presumably less easily decomposable, substances. The assumptions are not sound, however. Bearing in mind that the amount of carbon is ten times as great as that of nitrogen it is evident that the quantities of the two elements removed during the process must be in the same proportion if the ratio is even to remain constant. Nor is it certain that the residual substances would be more resistant to decomposing agents. Hydrolysis almost certainly proceeds *pari passu* with oxidation, and the hydrolysed products might be more, and not less, easily attacked. The rate of decomposition is associated rather with configuration than with percentage composition.

It is not surprising, then, that the ratio $C : N$ leads to no useful result in this case. No. 8 is altogether abnormal, the sample may not have been a good one, but this seems hardly likely. No. 9 is high, but the others give a value curiously near to the Rothamsted ratio, in spite of the great difference between the soils.

Calcium carbonate. The amounts of this substance are in the following order:

| | | | | | | | |
|--------------------|---|---|---|---|---|----|----|
| | 2 | 6 | 5 | 7 | 4 | 8 | 9, |
| omitting 7 | 2 | 6 | 5 | 4 | 8 | 9, | |
| order of oxidation | 7 | 2 | 5 | 6 | 4 | 8 | 9. |

No. 7 is a stiff clay, and hardly comparable with the others. Omitting this, the order is nearly the same for the percentage of calcium carbonate as for the rate of oxidation, and indeed the close connexion between these has already been shown. The remarkable feature is that the most productive plots, instead of having their stores of calcium carbonate depleted by the large crops they bear, actually contain more of this substance than the less fertile plots carrying smaller crops. How this has been brought about, and to what extent it is connected with their extra fertility, are questions we cannot now discuss.

Hygroscopic water. This may be taken to represent the water retained by the soil and not available for plant use. The order in which the soils are placed is

| | | | | | | | |
|--------------------|---|---|---|---|---|---|----|
| | 7 | 2 | 9 | 6 | } | 4 | 5, |
| | | | | 8 | | | |
| carbon | 7 | 2 | 8 | 9 | 6 | 5 | 4, |
| order of oxidation | 7 | 2 | 5 | 6 | 4 | 8 | 9. |

To some extent this order resembles the one derived from carbon determinations, and no doubt the hygroscopic water is connected with

the amount of organic matter. But until we have a fuller knowledge of the subject, there is no advantage in pursuing the somewhat elusive relationship between hygroscopic water and rate of oxidation.

The above discussion suffices to show that no single factor regulates the rate of oxidation. In this particular case the amounts of nitrogen and of calcium carbonate show a closer relationship with it than do the others, and with these soils they may perhaps be regarded as the dominant factors; but with other soils other conditions seemed to have a controlling effect.

In the foregoing pages no explanation has been offered of the connexion between oxidation and fertility. The method stands on a purely empirical basis—the same factors that influence fertility also influence the rate of oxidation, and apparently to the same extent. This basis is quite sufficient to justify its use in soil analysis quite apart from any explanation.

It may be of interest briefly to outline the hypothesis, which, in the view of the author, fits in best with all the facts. Presuming that the crops grown are adapted to the climate and to the general conditions prevailing, a fertile soil may be defined as one in which reactions take place so rapidly that the plant is abundantly supplied with food. Reactions may be hastened in three ways, the temperature may be raised, the concentration increased, or a catalytic agent employed; as a rule the first two methods are inapplicable in nature; high temperatures are obviously out of the question; the concentration of the soil solution cannot greatly increase, or its osmotic pressure becomes too high for the plant; and generally speaking, reactions in nature are accelerated by catalytic agents. Little is known of the catalytic action of the inorganic constituents of the soil, but there can be no question that the innumerable micro-organisms invariably present secrete enzymes which are powerful catalytic agents. When the concentration of the enzyme is small, as in the soil, action is more or less proportional to the amount present, and as enzymes in turn depend on the presence and activities of bacteria, moulds, fungi, etc., the number of these will be related to the amount of chemical action taking place. As most of the organisms in the surface layer are probably aerobic, a measure of their activity can be obtained from the rate at which oxygen is absorbed. A large oxygen absorption indicates a high activity of the micro-organisms, rapid chemical changes in the soil, and consequently a high state of fertility.

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The above dynamic definition differs essentially from the ordinary static definition, according to which productiveness is connected with the quantity of "available" food actually present at a given moment. It will, however, be found more useful.

The chemical actions taking place in the soil include the breaking down of organic matter and the simplification of phosphatic and potassic substances referred to by Ingle¹. The former are mainly enzymic or bacterial, the mechanism of the latter is not so clear. Some of the steps involved in the breaking down of the organic matter have been examined, and methods of soil analysis based upon them have been published. Thus Remy² measures the putrefying power of the soil, i.e. the rate at which organic matter is broken down to ammonia; Omeliansky³ measured the rate at which ammonia changes to nitrite and the nitrite to nitrate; Ashby simplifies matters by running from ammonia direct to nitrate without stopping at the nitrite stage⁴; and Beijerinck⁵ estimates the power of assimilating nitrogen. Whilst these determinations throw a flood of light on the separate bacterial processes taking place in the soil they cannot be expected to give much information about the total action, which according to the view taken here plays so important a part in determining fertility. The determinations are made in culture solutions so arranged as to favour one particular organism at the expense of the rest, optimum conditions are secured and maximum velocities obtained. The sum of these is not related to the actual speed of decomposition in the soil, any more than the sum of the velocity of a pony at a point to point race and of the Continental boat train is connected with the time actually required to drive to the station and make a cross country journey involving several changes. The study of the maximum speeds is of course essential for a complete solution of the problem, but some integrating method is also wanted to measure the total change actually taking place. The determination of the rate of oxidation is suggested as giving a useful indication of this total change, and therefore of the relative fertility of different soils.

It is clearly recognised that this view of fertility is not complete; no direct account is taken of the temperature and moisture conditions,

¹ *Journ. Chem. Soc.* 1905, Vol. LXXXVII. 43.

² *Cent. für Bakt. und Parasit.* 8, 660.

³ *Ibid.* 5, 539.

⁴ *Jour. Chem. Soc.* 1904, Vol. LXXXIV. 1158.

⁵ *Cent. für Bakt. und Parasit.* VII. 568.

which, in these experiments, were kept constant. The soil itself, isolated from its surroundings, is here being dealt with, and in interpreting the results it must be remembered that the surroundings may profoundly modify the productiveness of a naturally fertile soil. The ideal method would no doubt be to correct the oxidation values obtained in the laboratory by making simultaneous determinations *in situ*, the modifying effect of the conditions actually prevailing in the field would then be directly determined; unfortunately no practicable method of doing this has yet been devised. At the same time it is often of advantage to know in a particular case whether non-productiveness is due to a deficiency in the soil itself, or to some other condition, and here the method can give useful information.

CONCLUSIONS.

1. The rate at which oxygen is absorbed by a soil can be easily and accurately measured by the method here described.
2. The rate increases with the temperature, the amount of water (up to a certain point), and the amount of calcium carbonate, and is favoured by the conditions obtaining in the surface soil as opposed to those in the subsoil.
3. These are also the conditions favouring fertility. It is found that with different soils of the same type the rate of oxidation varies in the same way as the fertility, and may be used to measure it. Pasture soils are at present excluded, however.
4. It is suggested that the oxygen absorbed measures the total action of the micro-organisms, which, by producing enzymes and in other ways, hasten decomposition in the soil. Plant food is thus produced, and the general conditions are rendered more favourable for plant life. *Ceteris paribus*, the more rapid these changes the more productive the soil will be.

THE AMOUNTS OF NITROGEN AS AMMONIA AND AS
NITRIC ACID, AND OF CHLORINE IN THE RAIN-
WATER COLLECTED AT ROTHAMSTED.

By N. H. J. MILLER, Ph.D.

• (Lawes Agricultural Trust.)

At the time of the commencement of the Rothamsted experiments very little was known as to the amounts of combined nitrogen and other substances present in rain-water.

Marggraf (74) found nitric acid, chlorine and lime in rain-water collected during the winter of 1749–50, and, subsequently, in snow. These analyses, which are probably the earliest¹, were followed by those of Bergman (15) who detected the same substances both in rain and snow²; whilst somewhat later de Saussure (99) noticed the presence of ammonia in the atmosphere. Between 1820 and 1825 several analyses of rain-water were made. Hermbstaedt (54) detected organic matter, Mulder (84) and Zimmermann (125) found chlorine and several other substances in rain-water collected at Utrecht and near Giessen; whilst von Liebig found sometimes nitric acid and invariably ammonia in a number of samples which had been collected by Zimmermann. Brandes (24) determined the amount of total solids and detected the presence of chlorine, sulphuric acid, ammonia and other substances. By this time chlorine had already been determined by Dalton (37) in rain-water collected in Manchester. The first determinations of ammonia seem to be those of Payen (47) in 1845–6. From that date to 1855

¹ Evelyn, in his *Philosophical Discourse of Earth* (London, 1676), speaks of rains and dews as being "impregnated...with Celestial Nitre" (p. 98), and of "nitrous spirits descending with their baulmy pearls" (p. 174). This does not of course indicate that nitrates had actually been detected in rain, as the terms nitrous air &c. were applied at this period—the time of Mayow's and Hooke's experiments on combustion—to what is now known as oxygen.

² "Nivales aliquantulum calcis salitae cum exiguis acidi nitri vestigiis in sinu foveant... Pluviales iisdem plerumque materiis inquinantur, sed majori dosi" (*Opuscula*, i. 84).

numerous analyses of rain-water were made, chiefly in France, and although many of the determinations were then, and some even much later, made without reference to the magnitude of the rainfall, some, as for instance those of Boussingault and Barral, were made in measured amounts of the total fall, so that it became possible for the first time to estimate how much of the constituents determined was supplied to a given area of land in a given period.

During the last fifty years analyses of the rain have been made in most European countries and in many other parts of the world. With few exceptions, however, the analyses extend over very short periods and partly for this reason the results are frequently conflicting.

The earliest analyses of Rothamsted rain were made in 1853-4, when the nitrogen in the form of ammonia was determined (63). Further determinations, both of ammoniacal and nitric nitrogen, were made by Way in 1855 and 1856 (121). These earlier results have already been fully discussed elsewhere (64), but to make the present record complete they are given in Appendix Tables III and IV, which contain the whole of the results relating to nitrogen obtained up to the end of the harvest year 1904-1905.

The determinations of ammonia in monthly samples of the rain were recommenced in 1877, and were continued with some interruptions until December, 1885. Since January, 1888, however, ammonia has been regularly determined each month.

Nitric nitrogen has been determined uninterruptedly since September, 1886; for some months by Schloesing's method and, subsequently, by Williams' zinc-copper couple method¹. Chlorine has been determined each month since June, 1877 (Appendix Table V); and sulphuric acid, in mixed samples, representing winter and summer rain, from 1881 to 1887 (65 and 117).

Besides the monthly samples of rain, a large number of single samples have been analysed at Rothamsted (64), and in addition about 80 samples were analysed by the late Sir Edward Frankland (44).

NITROGEN AS AMMONIA AND AS NITRATES (AND NITRITES) IN ROTHAMSTED RAIN.

The average amounts of nitrogen in the forms of ammonia and nitric (and nitrous) acid in the Rothamsted rainfall during the thirteen harvest years, 1888-9 to 1900-1, is 3.84 lbs. per acre per

¹ *Trans. Chem. Soc.* 1881, 39, 100. For the minutiae of this and other methods employed at Rothamsted in the analysis of rain-water see Warington (118).

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annum, the relative amounts of ammoniacal and nitric nitrogen being 70 and 30 per cent. of the total. The greatest amount of nitrogen in these forms during the above period was 4.43 lbs. (1899-1900), and the lowest amount 3.31 lbs. The variations from year to year (see Table 1)

TABLE 1.
NITROGEN AS AMMONIA AND NITRIC ACID IN RAIN-WATER
COLLECTED AT ROTHAMSTED.

| September 1 to August 31 | Rainfall | Nitrogen | | | | | | |
|-----------------------------|----------|-----------------------|-------------------------------------|-----------------------|-------------------------------------|-------|-----------------------|-------------------------------------|
| | | Per million | | Per acre | | | % of Total | |
| | | as NH ₃ | as N ₂ O ₅ | as NH ₃ | as N ₂ O ₅ | Total | as NH ₃ | as N ₂ O ₅ |
| | inches | | | lb. | lb. | lb. | | |
| 1853-4* | 29.01 | 0.79 | — | 5.20 | — | — | — | — |
| 1855** | 29.17 | 0.88 | 0.11 | 5.82 | 0.72 | 6.54 | 89.0 | 11.0 |
| 1856** | 27.22 | 1.18 | 0.12 | 7.28 | 0.76 | 8.04 | 90.5 | 9.5 |
| 1881-2 | 32.31 | 0.33 | — | 2.443 | — | — | — | — |
| 1882-3 | 34.71 | 0.34 | — | 2.665 | — | — | — | — |
| 1883-4 | 25.77 | 0.40 | — | 2.334 | — | — | — | — |
| 1884-5 | 26.78 | 0.37 | — | 2.240 | — | — | — | — |
| 1886-7 | 23.61 | — | 0.138 | — | 0.736 | — | — | — |
| 1887-8 | 30.50 | — | 0.116 | — | 0.803 | — | — | — |
| 1888-9 | 30.09 | 0.412 | 0.134 | 2.806 | 0.911 | 3.717 | 75.5 | 24.5 |
| 1889-90 | 27.48 | 0.445 | 0.119 | 2.762 | 0.741 | 3.503 | 78.8 | 21.2 |
| 1890-1 | 23.41 | 0.483 | 0.195 | 2.560 | 1.033 | 3.593 | 71.2 | 28.8 |
| 1891-2 | 29.68 | 0.466 | 0.185 | 3.180 | 1.240 | 4.370 | 71.6 | 28.4 |
| 1892-3 | 28.94 | 0.535 | 0.217 | 2.914 | 1.185 | 4.099 | 71.1 | 28.9 |
| 1893-4 | 29.55 | 0.381 | 0.131 | 2.549 | 0.878 | 3.427 | 74.4 | 25.6 |
| 1894-5 | 28.94 | 0.364 | 0.161 | 2.397 | 1.068 | 3.465 | 69.2 | 30.8 |
| 1895-6 | 24.37 | 0.484 | 0.216 | 2.670 | 1.193 | 3.863 | 69.1 | 30.9 |
| 1896-7 | 37.24 | 0.350 | 0.160 | 2.947 | 1.346 | 4.293 | 68.6 | 31.4 |
| 1897-8 | 19.51 | 0.516 | 0.234 | 2.279 | 1.032 | 3.311 | 68.8 | 31.2 |
| 1898-9 | 24.69 | 0.443 | 0.228 | 2.474 | 1.276 | 3.750 | 66.0 | 34.0 |
| 1899-1900 | 31.02 | 0.431 | 0.200 | 3.028 | 1.401 | 4.429 | 68.4 | 31.6 |
| 1900-1 | 24.30 | 0.408 | 0.250 | 2.737 | 1.375 | 4.112 | 66.6 | 33.4 |

* March to February.

** January to December.

probably depend, in part, on the distribution of the rainfall, but seem to have no very definite relation to the total annual amount of rain. The lowest amount of nitrogen found during this period was, however, coincident with the lowest rainfall (19.51 inches in 1897-8). The

large amounts of nitrogen found in the rain collected in the years 1853-6, are evidently mainly due to the ammonia results being far too high. As has been pointed out elsewhere (64), the methods employed at that time left a good deal to be desired.

The amounts of nitrogen in the monthly samples of rain depend partly on the temperature and partly on the amount of rain. The smallest amount of nitrogen is found in February, being coincident with the lowest rainfall, whilst the largest amount occurs in August, when, in addition to an increased temperature, there is also a large amount of rain only exceeded in October.

TABLE 2.
AVERAGE MONTHLY AMOUNTS OF NITROGEN AS AMMONIA AND
NITRIC ACID IN ROTHAMSTED RAIN.

| 1888-9 to 1900-1 | Rainfall | Nitrogen | | | | | | |
|------------------|----------|-----------------------|-------------------------------------|-----------------------|-------------------------------------|-------|-----------------------|-------------------------------------|
| | | Per million | | Per acre | | | % of Total | |
| | | as NH ₃ | as N ₂ O ₅ | as NH ₃ | as N ₂ O ₅ | Total | as NH ₃ | as N ₂ O ₅ |
| | inches | | | lb. | lb. | lb. | | |
| September | 2.10 | 0.518 | 0.202 | 0.246 | 0.096 | 0.342 | 71.9 | 28.1 |
| October | 3.23 | 0.327 | 0.155 | 0.239 | 0.113 | 0.352 | 67.9 | 32.1 |
| November | 2.83 | 0.386 | 0.164 | 0.247 | 0.105 | 0.352 | 70.2 | 29.8 |
| December | 2.51 | 0.384 | 0.176 | 0.218 | 0.100 | 0.318 | 68.6 | 31.4 |
| January | 1.99 | 0.402 | 0.162 | 0.181 | 0.073 | 0.254 | 71.3 | 28.7 |
| February | 1.79 | 0.398 | 0.200 | 0.161 | 0.081 | 0.242 | 66.5 | 33.5 |
| March | 1.97 | 0.420 | 0.215 | 0.187 | 0.096 | 0.283 | 66.1 | 33.9 |
| April | 1.67 | 0.540 | 0.222 | 0.192 | 0.079 | 0.271 | 70.8 | 29.2 |
| May | 2.00 | 0.504 | 0.203 | 0.228 | 0.092 | 0.320 | 71.3 | 28.7 |
| June | 1.79 | 0.543 | 0.190 | 0.220 | 0.077 | 0.297 | 74.1 | 25.9 |
| July | 2.63 | 0.482 | 0.178 | 0.237 | 0.106 | 0.333 | 73.0 | 27.0 |
| August | 2.84 | 0.476 | 0.171 | 0.306 | 0.110 | 0.416 | 73.6 | 26.4 |
| Sept.—Dec. | 10.67 | 0.394 | 0.171 | 0.950 | 0.414 | 1.364 | 69.6 | 30.4 |
| Jan.—April | 7.32 | 0.435 | 0.199 | 0.721 | 0.329 | 1.050 | 68.7 | 31.3 |
| May—August ... | 9.26 | 0.497 | 0.184 | 1.041 | 0.385 | 1.426 | 73.0 | 27.0 |
| April—Sept. | 12.93 | 0.506 | 0.191 | 1.479 | 0.560 | 2.039 | 72.5 | 27.5 |
| Oct.—March | 14.32 | 0.381 | 0.175 | 1.233 | 0.568 | 1.801 | 68.5 | 31.5 |
| Whole year | 27.25 | 0.440 | 0.183 | 2.712 | 1.128 | 3.840 | 70.6 | 29.4 |

Of greater interest is the comparison of the summer with the winter rain. The rainfall itself of the two seasons does not differ

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materially in quantity, although the winter months show a slight excess over the summer. Reference to Table 2 will show that whilst in the winter the total nitrogen amounts to 1·80 lbs. per acre, the summer rain contains 2·04 lbs., the excess being entirely due to an increased production of ammonia, since the nitric nitrogen remains constant. Of the total nitrogen the summer rain contains 72·5 per cent. in the form of ammonia and 27·5 per cent. in the form of nitrates (and nitrites); the winter rain contains 68·5 per cent. and 31·5 per cent. respectively. In other words, to 1 part of nitric nitrogen there are 2·55 parts of ammoniacal nitrogen in the summer, and only 2·15 parts in the winter months.

The influence of the amount of the rainfall on the composition of the rain is illustrated by the results given in Table 3, which shows the average amounts of nitrogen in the two forms in monthly samples of rain below 1 inch, and above 4 inches respectively during the last thirteen years. It happens that in both cases there were exactly the same number of samples (eighteen).

TABLE 3.
NITROGEN AS AMMONIA AND NITRIC ACID IN
MONTHLY RAINFALLS.

| | Rainfall below 1 inch | | | Rainfall above 4 inches | | |
|----------|-----------------------|----------------|-------------|-------------------------|----------------|-------------|
| | Rainfall | N. per million | | Rainfall | N. per million | |
| | | as Ammonia | as Nitrates | | as Ammonia | as Nitrates |
| | inches | | | inches | | |
| Min. ... | 0·09 | 6·236 | 2·161 | 4·03 | 0·314 | 0·140 |
| Max. ... | 0·96 | 0·686 | 0·285 | 8·08 | 0·224 | 0·090 |
| Mean ... | 0·65 | 0·965 | 0·442 | 4·92 | 0·278 | 0·124 |

As was to be expected from the relatively greater variations in the amounts of rainfall below 1 inch, the amounts of nitrogen also differ widely; the average amount of nitrogen per million in the low rainfall is, however, more than twice as high as in the higher rainfall.

Comparing the amount of total nitrogen in the Rothamsted rain with the amounts found, during the past forty years, in various parts

of the world (Table 4), the majority of the results are a good deal higher than those just described. In a few cases, notably Paris and Copenhagen, this may no doubt be attributed to the rain having been collected in, or near large towns. It was to be hoped that the considerable number of results now brought together would enable some kind of grouping to be made; that, for instance, the total nitrogen would show, at any rate in extreme cases, some relation to the rainfall, or would be influenced by proximity to, or distance from, the sea. It is evident, however, that whilst the total nitrogen may vary enormously under apparently quite similar climatic conditions, differences of climate are not necessarily coincident with great variation in the composition of the rain. The rain, for instance, collected at Manhattan, which is about 700 miles from the Gulf of Mexico and more than 1,100 miles from the Pacific, closely resembles the Rothamsted rain. Then again, the 102 inches of rain which fall in British Guiana do not supply to the soil more, but rather less, nitrogen than the 27 inches at Rothamsted.

It will, however, be convenient to consider separately the rain falling in temperate and in tropical countries.

In non-tropical rain the relation of ammoniacal to nitric nitrogen varies less, perhaps, than might be expected from the differences in the amounts of total nitrogen, and the average of all the results recorded in the table (p. 286) is very similar to that found at Rothamsted. With the one exception of New Zealand, the ammonia is greatly in excess of the nitric acid. In the rain of Lincoln, New Zealand, the relation is reversed, the nitric nitrogen being in excess, as in the case of some tropical rains. This resemblance is, however, only partial, since the relation of ammonia nitrogen to nitric nitrogen in New Zealand rain is not due to a high amount of nitrates, but to an unusually small amount of ammonia. This is possibly due to the prevalence of sea-winds, as it has been pointed out by Anderlind (2) that the results obtained by Merino (79) in the north-west of Spain show less ammonia when the wind is from the sea than during an overland wind. Heinrich obtained similar indications at Rostock (53). On the other hand Schloesing believes that the sea is the chief source of the ammonia present in the air.

Exceptionally high relations of ammonia to nitric acid occur in the case of Ploty (122) and Pretoria (113); whilst the rain collected at Tokio shows a decidedly low proportion of ammonia to nitric acid. The results obtained at the ten different places (excluding New Zealand) at

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TABLE 4.

NITROGEN AS AMMONIA AND NITRIC ACID IN RAIN.

| | Date | Rainfall | Nitrogen | | | | | |
|------------------------------|--------------------|----------|-----------------------|-------------------------------------|-----------------------|-------------------------------------|-------|------------|
| | | | Per million | | Per acre per annum | | | % of Total |
| | | | as NH ₃ | as N ₂ O ₅ | as NH ₃ | as N ₂ O ₅ | Total | |
| | | inches | | | lb. | lb. | lb. | |
| Rothamsted..... | { 1888-9 1900-1 | 27.25 | 0.440 | 0.183 | 2.71 | 1.13 | 3.84 | 70.6 |
| Copenhagen (114) | 1880-85 | 21.95 | 1.97 | 0.473 | 9.27 | 2.21 | 11.48 | 80.8 |
| Gembloux (93)..... | 1889-91 | 27.23 | 1.143 | 0.345 | 7.07 | 2.14 | 9.21 | 76.8 |
| Montsouris (67) | 1876-1900 | 21.52 | 2.13 | 0.66 | 10.37 | 3.22 | 13.59 | 76.3 |
| Mettray (66) | 1877 | 29.90 | 0.409 | — | 2.77 | — | — | — |
| Dahme (39) | 1865 | 17.09 | 1.42 | 0.30 | 5.50 | 1.16 | 6.66 | 82.6 |
| Ida-Marienhütte (25) | 1865-70 | 22.65 | — | — | — | — | 9.92 | — |
| Insterburg (39) | 1864-6 | 25.67 | 0.65 | 0.38 | 3.90 | 2.25 | 6.15 | 63.1 |
| Kuschen (39) | 1864-6 | 14.78 | 0.48 | 0.16 | 1.63 | 0.55 | 2.18 | 75.0 |
| Proskau (39) | 1864-5 | 17.81 | 3.21 | 1.73 | 12.94 | 6.97 | 19.91 | 65.0 |
| Regenwalde (39) | 1864-7 | 22.72 | 2.08 | 0.62 | 10.69 | 3.28 | 13.97 | 77.0 |
| Rostock (53) | 1880-1 | 33.27 | 0.892 | — | 6.73 | — | — | — |
| Florence (11) | 1869-75 | 33.31 | 1.004 | 0.57 | 8.70 | 3.09 | 11.79 | 73.8 |
| Vallombrosa (11) | 1872-5 | 59.89 | 0.617 | 0.253 | 8.36 | 3.46 | 11.82 | 70.7 |
| Scandicci (90) | 1888-90 | 29.18 | 0.614 | 0.266 | 4.06 | 1.76 | 5.82 | 69.8 |
| Catania (10) | 1888-9 | 18.36 | 0.327 | 0.161 | 1.36 | 0.67 | 2.03 | 66.9 |
| St Michele, Tirol (69) | 1885-6 | 43.93 | 1.183 | 0.579 | 11.83 | 5.76 | 17.59 | 67.3 |
| Libwerd, Bohemia | 1877-8 | 24.41 | 1.3 | 0.61 | 7.18 | 3.37 | 10.55 | 68.1 |
| Peček, " | 1883-4 to 85-6 | 19.34 | 1.26 | 0.50 | 5.53 | 2.19 | 7.72 | 71.6 |
| Ploty (122) | 1900-3 | 17.49 | 0.854 | 0.061 | 3.38 | 0.24 | 3.62 | 93.3 |
| Pretoria (113) | 1904* | — | 0.68 | 0.12 | — | — | — | 85.1 |
| Tokio (59) | 1883-4 | 52.67 | — | 0.093 | — | 1.11 | 2.88 | 61.6 |
| " | 1885 | 62.28 | 0.126 | — | 1.77 | — | — | — |
| New Zealand (51) | 1884-8 | 29.70 | 0.076 | 0.169 | 0.50 | 1.13 | 1.63 | 30.7 |
| Kansas (42) | 1887-9 | 29.41 | 0.393 | 0.154 | 2.62 | 1.03 | 3.64 | 71.8 |
| Mississippi (112) | 1894-5 | 44.11 | 0.235 | 0.074 | 2.35 | 0.74 | 3.09 | 76.0 |

TROPICAL RAIN.

| | | | | | | | | |
|-----------------------------|-----------|--------|-------|-------|-------|------|-------|------|
| Calcutta | 1891 | 46.01 | 0.172 | 0.115 | 1.79 | 1.20 | 2.99 | 59.7 |
| Madras | 1888-93 | 39.21 | — | — | — | — | 1.91 | — |
| Ceylon (4) | 1893-9 | 82.13 | 0.196 | 0.069 | 3.65 | 1.28 | 4.93 | 72.0 |
| East Java (75) | 1891 | (47) | 0.11 | 0.06 | 1.13 | 0.71 | 1.84 | 61.5 |
| Mauritius (21) | 1895 | (70) | 0.43 | 0.40 | 6.81 | 6.34 | 13.15 | 51.8 |
| Réunion (88) | 1886-7 | (40) | — | 0.69 | — | 6.24 | — | — |
| Barbados (5) | 1885-97 | 63.95 | 0.084 | 0.268 | 1.22 | 3.88 | 5.10 | 23.9 |
| Venezuela (71 and 88) | 1883-5 | (40) | 1.55 | 0.58 | 14.03 | 5.20 | 19.23 | 72.8 |
| British Guiana † (52) | 1890-1900 | 102.41 | 0.055 | 0.078 | 1.17 | 1.82 | 2.99 | 39.1 |
| Campinas (30) | 1890 | — | 0.99 | — | — | — | — | — |

* Feb. to June only. † In part unpublished. Communicated by Prof. J. B. Harrison.

which analyses have been continued for at least four years, give an average of 73·5 of nitrogen as ammonia to 26·5 nitric nitrogen.

As regards the tropics, the rain collected in British Guiana and Barbados contains a large excess of nitric over ammoniacal nitrogen, attributed by Harrison (52) to the prevalence of violent thunderstorms. In Mauritius, however, there is a slight excess of nitrogen in the form of ammonia; whilst the rain collected at Caracas, Venezuela, at Calcutta, and at Colombo contains a more or less considerable excess of ammoniacal nitrogen in relation to nitric nitrogen.

The only explanation of these differences seems to be the one offered in the case of New Zealand rain, but this leaves quite unaccounted for the discrepancies shown in the rain of Java and Mauritius and again in that of British Guiana and Venezuela.

The one conclusion which may safely be drawn is that tropical rain does not supply to the soil an essentially greater amount of nitrogen than the rain of temperate climates. The average for the seven tropical places in which both forms of nitrogen have been determined is 7·2 lbs. of nitrogen per acre per annum. And this includes the exceptional amounts found at Caracas and in Mauritius. When these abnormal results are omitted the average total nitrogen for tropical countries is only 3·58 lbs. per acre, with a high average rainfall of 68·3 inches.

NITROGEN AS NITROUS ACID IN RAIN.

The nitrogen in the form of nitrites has not been separately determined in the rain at Rothamsted, being included along with the nitrates, by the reduction method employed; and very few determinations seem to have been made elsewhere. Such results, however, as are available (Table 5) indicate that the amounts of nitrogen present in this form are usually insignificant.

The results of qualitative experiments made by Failyer and Willard with rain collected at Manhattan (42) showed that from December to March only 28 per cent. of the samples contained nitrous nitrogen, whilst from June to September 89 per cent. of the samples gave positive results. There is, however, no evidence to show whether the conditions of the summer months are favourable to the production or merely to the conservation of nitrites.

With regard to the amount of organic nitrogen in the rain-water, the only available analyses relating to Rothamsted are those of

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Frankland who found from 0·03 to 0·66 per million in 69 samples. The average amount (0·19 per million) equalled rather more than one-third of the nitrogen present in the forms of ammonia and nitric acid (0·51 per million). The total nitrogen in the Rothamsted rain is, therefore, 3·84 + 1·35 lb., or about 5·2 lb. per acre per annum.

In rain-water collected in New Zealand, Gray found 0·45 lb. of albuminoid nitrogen per acre per annum.

TABLE 5.
NITROGEN AS NITROUS AND NITRIC ACIDS IN RAIN AND SNOW.

| | Rainfall | Nitrogen | | | | | | | |
|----------------------|----------|-------------|--------|--------|-------------|-------|-------|-------------|------------|
| | | Per million | | | | | | Per acre | |
| | | as Nitrites | | | as Nitrates | | | as Nitrites | as Nitrate |
| | | Min. | Max. | Mean | Min. | Max. | Mean | | |
| | inches | | | | | | | lb. | lb. |
| St Chamas (31)..... | (20) | 0·0 | 0·316 | 0·133 | 0·001 | 0·716 | 0·162 | (0·60) | (0·73) |
| " (snow)..... | — | — | — | 0·250 | — | — | — | — | — |
| Langres (31) „ .. | — | — | — | 0·270 | — | — | 0·881 | — | — |
| Scandicci (90) | 27·28 | 0·0 | 0·0168 | 0·0045 | 0·033 | 0·729 | 0·255 | 0·028 | 1·687 |
| Catania (10) | 18·36 | 0·0001 | 0·0027 | 0·0006 | 0·035 | 0·244 | 0·161 | 0·003 | 0·671 |
| Ploty (122)..... | 17·49 | 0·0 | 0·025 | 0·011 | 0·002 | 0·178 | 0·050 | 0·043 | 0·187 |

In addition to the nitrogen brought to the soil by rain, Schloesing (104) has shown that soils may absorb as much as 47 kilos. of nitrogen per hectare per annum directly from the air. He found that the character of the soil has no great influence on the absorption, but that the presence of moisture acts favourably owing to the increased nitrification of the ammonia absorbed, and the resulting reduction of the tension of the ammonia in the soil. Employing 20 per cent. hydrochloric acid as the absorbent, Heinrich (53) found that the ammonia thus fixed amounted to 30·6 kilos. per hectare; but he considers that the absorption would probably be less over a large surface, and that the calculation per hectare from a small experiment is not altogether admissible. Müller (84) and Kellner (59), who both employed dilute sulphuric acid, obtained results indicating an absorption of only 12 and 13 kilos. respectively of nitrogen per hectare per annum. As these amounts include a certain

quantity of ammonia—perhaps most of it—originally derived from the soil, some of which would, under ordinary conditions, be brought down by the rain, the actual gain due to direct absorption must be less than that indicated by experiments such as those referred to.

CHLORINE AND SULPHURIC ACID.

As already stated the chlorine in the monthly samples of rain has been determined since 1877-8, that is to say for 28 years. The annual amounts of chlorine per acre show great variations, which are to a great extent independent of the total yearly rainfall.

| | Date | Rainfall | Chlorine | |
|-----------------------|---------|----------|-------------|----------|
| | | | Per million | Per acre |
| | | inches | | lb. |
| Minimum rainfall..... | 1897-8 | 19.51 | 3.74 | 16.51 |
| Maximum „ | 1878-9 | 41.05 | 1.69 | 15.73 |
| Minimum chlorine ... | 1889-90 | 27.43 | 1.66 | 10.32 |
| Maximum „ | 1896-7 | 37.24 | 2.51 | 21.19 |

The maximum and minimum annual rainfalls show, therefore, no very material difference in the amounts of chlorine per acre (both are somewhat in excess of the average), and results may be obtained, quite independently of the total rainfall, which differ by 100 per cent., and are evidently mainly due, on the one hand to a deficiency, and on the other to an excess of rain during the winter months, the rainfall of which, as will presently be shown, contains more than twice as much chlorine per million as that of the summer months.

The amount of chlorine per million varies with considerable regularity from month to month. The lowest amount occurs in July, after which there is a rise until January, when the highest amount is reached. In February there is a drop, followed by a rise in March and then by a fall until July. The amounts per acre show similar variations but with somewhat less regularity.

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TABLE 6.

AVERAGE AMOUNT OF CHLORINE IN ROTHAMSTED RAIN.

| 1877-8 to 1900-1901 | Rainfall (average 24 years) Inches | Chlorine | |
|------------------------------|--|-------------|----------------|
| | | Per million | Per acre (lb.) |
| September | 2.46 | 1.62 | 0.90 |
| October | 3.24 | 2.46 | 1.80 |
| November | 3.03 | 2.71 | 1.86 |
| December | 2.50 | 3.27 | 1.85 |
| January | 2.06 | 3.80 | 1.77 |
| February | 2.03 | 3.05 | 1.40 |
| March | 1.79 | 3.56 | 1.44 |
| April | 1.91 | 2.22 | 0.96 |
| May | 2.16 | 1.76 | 0.86 |
| June | 2.22 | 1.29 | 0.65 |
| July | 2.59 | 1.06 | 0.62 |
| August | 2.79 | 1.20 | 0.76 |
| Summer (April—September) ... | 14.13 | 1.49 | 4.75 |
| Winter (October—March) | 14.65 | 3.05 | 10.12 |
| Whole year | 28.78 | 2.28 | 14.87 |

With regard to the relation between the quantity of the monthly rainfall and the amount of chlorine, the results (see Table 7) show a regular decrease in the chlorine as the rainfall increases, although not in the

TABLE 7.

AVERAGE AMOUNTS OF CHLORINE IN MONTHLY RAINFALLS GROUPED
ACCORDING TO THE AMOUNT OF THE FALL.

| | Whole Year | | | Winter | | | Summer | | |
|-------------|--------------------------|----------------|-------------|--------------------------|----------------|-------------|--------------------------|----------------|-------------|
| | Average Rain- fall | Chlorine | | Average Rain- fall | Chlorine | | Average Rain- fall | Chlorine | |
| | | Per million | Per acre | | Per million | Per acre | | Per million | Per acre |
| | inches | | lb. | inches | | lb. | inches | | lb. |
| Below 1 in. | 0.72 | 4.11 | 0.67 | 0.74 | 4.95 | 0.83 | 0.67 | 3.23 | 0.49 |
| 1-2 inches | 1.43 | 3.06 | 0.99 | 1.46 | 3.93 | 1.30 | 1.41 | 2.19 | 0.70 |
| 2-3 inches | 2.51 | 2.34 | 1.33 | 2.52 | 3.28 | 1.87 | 2.46 | 1.53 | 0.85 |
| 3-4 inches | 3.52 | 2.24 | 1.78 | 3.51 | 2.76 | 2.19 | 3.53 | 1.41 | 1.13 |
| Above 4 in. | 4.99 | 1.59 | 1.80 | 4.89 | 2.44 | 2.70 | 5.08 | 0.86 | 0.99 |

same proportion, the rate of decrease in the chlorine being much less than the rate of increase in the rain. In this respect the summer and winter rains show great difference. In the summer the monthly rainfalls of 4 inches or more (average 5.08 inches) contain about a quarter as much chlorine per million as is found in the rainfalls of less than 1 inch (average 0.67 inch). With corresponding winter rainfalls the higher amounts of rain contain half as much chlorine as the lower.

No recent determinations of sulphuric acid have been made in the rain at Rothamsted. In the following table is a summary of the results obtained in 1881-7, with the chlorine results, for the same period, for comparison.

TABLE 8.

SULPHURIC ACID AND CHLORINE IN ROTHAMSTED RAIN.

| April 1881 to March 1887 | Rainfall | Per million | | Per acre | | SO ₂ to 1 Cl |
|-----------------------------|----------|-------------|-----------------|----------|-----------------|----------------------------|
| | | Cl | SO ₂ | Cl | SO ₂ | |
| | inches | | | lb. | lb. | |
| April to September | 13.90 | 1.31 | 2.77 | 4.11 | 8.71 | 2.12 |
| October to March | 16.05 | 2.89 | 2.39 | 10.51 | 8.70 | 0.63 |
| Whole year | 29.95 | 2.16 | 2.57 | 14.62 | 17.41 | 1.19 |

The similarity of the amounts of sulphuric acid in the summer and winter rain is very striking, especially in view of the great variation in the chlorine results. The slightly higher results obtained in the summer as compared with the winter accord with observations made by Russell in London, and support the view that the sulphuric acid is to a great extent an oxidised product of the decomposition of organic matters. Very little of it can be derived from the sea, since the relation of sulphuric acid to chlorine in sea-water is only 11 : 100; and Russell found that rain-water from Dartmoor collected during a strong sea-wind contained only a trace of sulphuric acid.

Compared with London rain the amount of sulphuric acid found at Rothamsted is small; but it is somewhat in excess of the amount found in New Zealand. Sestini found 5.02 per million, equivalent to 20.89 lb. per acre, in the rain collected at Catania.

TABLE 9.

CHLORINE AND SULPHURIC ACID IN RAIN.

| | Date | Rainfall | Per million | | | | Per acre | | So. to 100 |
|---------------------|-------------------|-----------------|-------------|---------|--------|------------------------|--------------|------------------------|------------------|
| | | | Chlorine | | | Sul- phuric acid | Chlorine | Sul- phuric acid | |
| | | | Min. | Max. | Mean * | | | | |
| Rothamsted | 1877-8) 1900-1 | inches 28.78 | 0.40 | 20.10 | 2.28 | 2.57* | lb. 14.87 | 14.87 | 1.16 |
| Cirencester (60) | 1874-1900 | 30.61 | 1.15 | 10.38 | 3.17 | — | 21.90 | — | — |
| Scandicci (91) | 1889-91 | 27.67 | 0.17 | 31.95 | 5.63 | — | 35.35 | — | — |
| Perugia (14) | 1886-7 | 33.96 | 1.38 | 40.28 | 3.15 | — | 24.22 | — | — |
| Catania (10) | 1888-9 | 18.36 | 1.47 | 7.36 | 5.48 | 5.02 | 22.79 | 20.89 | 94% |
| La Guardia (79) | 1892-3 | 56.42 | 7.1 | 71.9 | 31.2 | — | 399.5 | — | — |
| New Zealand (51) | 1884-8 | 29.70 | 2.6 | 36.4 | 8.83 | 2.22 | 59.44 | 14.94 | 0.25 |
| Barbados (5) | 1885-97 | 63.95 | 3.55 | 33.97 | 8.14 | — | 127.8 | — | — |
| British Guiana (52) | 1890-1900 | 102.41 | (1.68) | (17.68) | 5.04 | — | 116.88 | — | — |
| Ceylon (4) | 1898-9 | 82.13 | — | — | 9.72 | — | 180.63 | — | — |
| Calcutta | 1894 | 46.01 | 1.82 | 5.44 | 3.16 | — | 32.87 | — | — |
| Madras | 1888-93 | 39.21 | — | — | 4.08 | — | 36.27 | — | — |

* 1881-87.

All the very high chlorine results recorded in Table 9 are to be accounted for by proximity to the sea. In this connexion it may be mentioned that Frankland found as much as 218 parts of chlorine per million in rain collected at Land's End, at a height of about 100 feet above the sea.

It has been pointed out by Kinch (60) that the quantity of chlorine brought down by the rain at Rothamsted and at Cirencester is sufficient for the requirements of most crops. The same may be said as regards the sulphuric acid in the rain at Rothamsted.

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APPENDIX—TABLE I.

SUMMARY OF METEOROLOGICAL OBSERVATIONS AT ROTHAMSTED.

| | Rainfall, Average 53 years 1852-1905 | | Bright sunshine, Average 15 years 1890-1905 | | Temperature, Average 27 years 1878-1905 | | |
|----------------|--|---------------------------|---|--------------|---|---------|---------|
| | Total | Days with 0·01 inch | Total | Per cent. | Min. | Max. | Mean |
| | inches | | hours | | deg. F. | deg. F. | deg. F. |
| September..... | 2·49 | 13 | 160·5 | 43 | 47·5 | 64·1 | 55·8 |
| October | 3·18 | 18 | 107·0 | 33 | 41·1 | 54·9 | 48·0 |
| November | 2·62 | 16 | 58·8 | 23 | 36·7 | 48·3 | 42·5 |
| December | 2·33 | 16 | 41·8 | 18 | 32·4 | 42·9 | 37·7 |
| January..... | 2·36 | 16 | 51·6 | 21 | 31·4 | 41·7 | 36·5 |
| February | 1·80 | 13 | 72·8 | 27 | 32·5 | 43·9 | 38·2 |
| March | 1·84 | 13 | 117·5 | 32 | 33·5 | 48·3 | 40·9 |
| April | 1·86 | 13 | 160·1 | 39 | 37·0 | 54·2 | 45·6 |
| May | 2·19 | 13 | 195·2 | 40 | 42·1 | 60·2 | 51·1 |
| June | 2·38 | 12 | 196·3 | 40 | 48·3 | 66·4 | 57·4 |
| July | 2·59 | 13 | 217·4 | 44 | 51·8 | 70·0 | 60·9 |
| August | 2·67 | 14 | 199·0 | 44 | 51·1 | 68·4 | 59·8 |
| Year..... | 28·31 | 170 | 1578·0 | 34 | 40·5 | 55·3 | 47·9 |

APPENDIX—TABLE II.

RAINFALL AT ROTHAMSTED.

| | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May | June | July | Aug. | Year |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | inches | inches | inches | inches | inches | inches | inches | inches | inches | inches | inches | inches | inches |
| 1852-3 | — | — | — | — | — | — | 2.36 | 3.00 | 1.68 | 3.40 | 4.48 | 2.98 | — |
| 1853-4 | 2.01 | 3.66 | 2.05 | 0.41 | 2.03 | 0.95 | 0.51 | 0.50 | 4.38 | 0.76 | 1.05 | 2.82 | 21.13 |
| 1854-5 | 0.78 | 2.29 | 1.53 | 1.76 | 0.60 | 0.99 | 2.36 | 0.41 | 2.32 | 1.65 | 6.96 | 2.63 | 24.28 |
| 1855-6 | 1.55 | 5.50 | 2.47 | 1.72 | 2.78 | 1.35 | 1.00 | 2.61 | 4.71 | 1.91 | 1.48 | 2.65 | 29.73 |
| 1856-7 | 2.19 | 2.87 | 1.42 | 2.24 | 3.71 | 0.57 | 1.48 | 2.16 | 1.11 | 2.22 | 1.61 | 3.08 | 24.46 |
| 1877-8 | 1.53 | 1.95 | 5.16 | 2.28 | 1.75 | 1.80 | 0.98 | 4.09 | 4.97 | 2.51 | 0.65 | 4.98 | 32.65 |
| 1878-9 | 1.46 | 2.99 | 4.55 | 1.60 | 2.85 | 3.80 | 1.18 | 2.79 | 3.48 | 5.55 | 4.24 | 6.56 | 41.05 |
| 1879-80 | 3.13 | 0.82 | 0.81 | 0.82 | 0.55 | 2.90 | 1.13 | 2.16 | 0.74 | 1.97 | 5.26 | 1.07 | 21.26 |
| 1880-1 | 5.86 | 5.94 | 2.92 | 3.47 | 1.14 | 3.70 | 2.15 | 1.00 | 1.38 | 1.63 | 1.76 | 5.82 | 36.77 |
| 1881-2 | 2.17 | 3.05 | 3.47 | 4.38 | 1.57 | 2.02 | 1.57 | 3.92 | 2.07 | 3.93 | 2.09 | 2.07 | 32.31 |
| 1882-3 | 2.29 | 6.52 | 3.44 | 3.28 | 3.30 | 4.34 | 0.89 | 1.48 | 1.89 | 2.23 | 4.21 | 0.84 | 34.71 |
| 1883-4 | 3.99 | 2.49 | 3.52 | 1.16 | 2.56 | 1.42 | 1.66 | 1.79 | 0.64 | 2.50 | 2.44 | 1.60 | 25.77 |
| 1884-5 | 2.18 | 1.70 | 2.05 | 3.06 | 2.99 | 2.85 | 1.46 | 2.88 | 2.88 | 2.76 | 0.38 | 1.59 | 26.74 |
| 1885-6 | 4.89 | 4.82 | 3.77 | 1.33 | 3.44 | 0.61 | 1.59 | 1.96 | 4.24 | 1.23 | 2.42 | 1.22 | 31.02 |
| 1886-7 | 1.51 | 3.94 | 2.77 | 4.21 | 2.39 | 0.95 | 1.76 | 1.19 | 2.35 | 0.71 | 0.79 | 1.04 | 23.61 |
| 1887-8 | 3.11 | 1.69 | 3.41 | 1.66 | 0.94 | 1.03 | 3.13 | 2.14 | 1.28 | 4.87 | 3.86 | 3.38 | 39.30 |
| 1888-9 | 1.03 | 1.09 | 4.45 | 1.69 | 1.29 | 1.95 | 1.89 | 2.47 | 5.00 | 1.38 | 5.67 | 2.18 | 39.08 |
| 1889-90 | 2.44 | 3.62 | 1.21 | 1.46 | 2.94 | 0.82 | 2.78 | 1.31 | 1.38 | 2.40 | 4.56 | 2.51 | 27.43 |
| 1890-1 | 1.20 | 1.57 | 2.76 | 0.56 | 2.25 | 0.09 | 1.76 | 1.50 | 3.46 | 1.89 | 2.34 | 4.03 | 23.41 |
| 1891-2 | 1.39 | 6.76 | 2.25 | 4.13 | 1.01 | 1.48 | 1.22 | 0.79 | 1.40 | 2.56 | 3.00 | 3.69 | 29.68 |
| 1892-3 | 2.46 | 3.99 | 2.06 | 1.63 | 2.05 | 3.62 | 0.42 | 0.25 | 1.22 | 1.00 | 3.00 | 2.38 | 24.08 |
| 1893-4 | 1.14 | 4.46 | 2.92 | 2.63 | 2.38 | 1.96 | 2.19 | 1.71 | 2.07 | 2.01 | 2.40 | 3.68 | 29.53 |
| 1894-5 | 2.22 | 3.45 | 4.98 | 2.18 | 2.23 | 0.19 | 1.91 | 1.47 | 0.69 | 0.45 | 5.12 | 4.05 | 28.94 |
| 1895-6 | 1.06 | 2.69 | 4.96 | 2.34 | 1.12 | 0.59 | 3.75 | 0.95 | 0.48 | 2.25 | 1.27 | 2.91 | 24.37 |
| 1896-7 | 8.08 | 4.13 | 1.39 | 4.42 | 2.03 | 2.92 | 4.20 | 1.91 | 1.72 | 2.73 | 0.47 | 3.24 | 37.24 |
| 1897-8 | 2.44 | 0.96 | 1.05 | 3.50 | 0.80 | 1.10 | 1.06 | 1.44 | 2.89 | 1.61 | 1.45 | 1.21 | 19.51 |
| 1898-9 | 0.60 | 2.89 | 2.44 | 3.01 | 2.96 | 2.44 | 0.87 | 2.73 | 2.81 | 1.58 | 1.28 | 1.09 | 24.70 |
| 1899-1900 | 2.46 | 3.75 | 3.76 | 1.41 | 3.67 | 4.91 | 0.96 | 1.33 | 1.08 | 2.63 | 1.13 | 3.93 | 31.02 |
| 1900-1 | 0.84 | 2.60 | 2.60 | 3.65 | 1.18 | 1.26 | 2.57 | 2.51 | 1.81 | 0.84 | 2.44 | 2.00 | 24.30 |
| 1901-2 | 1.35 | 2.03 | 1.05 | 4.13 | 0.63 | 1.25 | 1.49 | 0.83 | 2.20 | 3.33 | 1.24 | 3.53 | 23.26 |
| 1902-3 | 1.05 | 1.88 | 1.95 | 1.39 | 2.55 | 1.06 | 3.47 | 1.53 | 2.22 | 6.12 | 4.08 | 3.96 | 31.26 |
| 1903-4 | 2.75 | 6.32 | 2.21 | 2.42 | 3.50 | 3.45 | 1.58 | 1.25 | 2.15 | 0.81 | 2.92 | 2.15 | 31.51 |
| 1904-5 | 1.59 | 1.37 | 1.67 | 2.48 | 1.34 | 0.95 | 3.57 | 2.22 | 1.13 | 4.05 | 1.47 | 3.46 | 25.39 |

APPENDIX—TABLE III.

NITROGEN AS AMMONIA IN RAIN-WATER COLLECTED AT ROTHAMSTED
IN PARTS PER MILLION.

| | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May | June | July | Aug. | Year |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1852-3 | — | — | — | — | — | — | 1.19 | 0.67 | 1.10 | 1.05 | 0.77 | 0.69 | — |
| 1853-4 | 0.61 | 0.57 | 0.66 | 1.33 | 0.64 | 0.78 | 0.78 | 0.80 | 0.37 | — | — | — | — |
| 1854-5 | — | — | — | — | 1.08 | 1.22 | 1.01 | 1.45 | 0.94 | 1.59 | 0.72 | 0.94 | — |
| 1855-6 | 1.12 | 0.72 | 0.64 | 0.79 | 0.93 | 1.60 | 1.09 | 1.72 | 1.49 | 1.33 | 1.00 | 0.82 | 1.08 |
| 1856-7 | 1.42 | 0.71 | 0.94 | 0.94 | — | — | — | — | — | — | — | — | — |
| 1877-8 | — | 0.350 | — | — | — | — | 0.357 | 0.466 | — | — | — | — | — |
| 1878-9 | 0.576 | — | — | — | 0.219 | 0.298 | 0.638 | 0.617 | 0.470 | 0.384 | — | — | — |
| 1879-80 | 0.412 | 0.988 | — | 1.088 | 0.495 | 0.371 | 0.371 | 0.881 | 1.276 | 0.508 | 0.309 | — | — |
| 1880-1 | 0.160 | 0.165 | — | 0.162 | 0.659 | 0.467 | — | 0.604 | 0.631 | 0.412 | 0.618 | 0.178 | — |
| 1881-2 | 0.350 | 0.214 | 0.237 | 0.196 | 0.422 | 0.227 | 0.313 | 0.319 | 0.535 | 0.445 | 0.503 | 0.453 | 0.334 |
| 1882-3 | 0.401 | 0.254 | 0.137 | 0.360 | 0.213 | 0.199 | 0.856 | 0.576 | 0.412 | 0.391 | 0.432 | 0.725 | 0.389 |
| 1883-4 | 0.362 | 0.280 | 0.190 | 0.824 | 0.268 | 0.453 | 0.412 | 0.617 | 0.617 | 0.576 | 0.350 | 0.463 | 0.400 |
| 1884-5 | 0.275 | 0.412 | 0.361 | 0.230 | 0.319 | 0.213 | 0.453 | 0.535 | 0.350 | 0.350 | 1.071 | 0.638 | 0.370 |
| 1885-6 | 0.178 | 0.247 | 0.275 | 0.577 | — | — | — | — | — | — | — | — | — |
| 1887-8 | — | — | — | 0.337 | — | 0.538 | 0.315 | 0.600 | 0.256 | 0.500 | 0.388 | 0.288 | — |
| 1888-9 | 1.025 | 0.525 | 0.313 | 0.500 | 0.575 | 0.238 | 0.400 | 0.575 | 0.300 | 0.378 | 0.350 | 0.538 | 0.412 |
| 1889-90 | 0.625 | 0.338 | 0.625 | 0.413 | 0.363 | 0.625 | 0.288 | 0.600 | 0.625 | 0.463 | 0.363 | 0.425 | 0.445 |
| 1890-1 | 0.775 | 0.475 | 0.225 | 1.300 | 0.450 | 0.250 | 0.550 | 0.625 | 0.350 | 0.719 | 0.417 | 0.313 | 0.483 |
| 1891-2 | 0.594 | 0.300 | 0.495 | 0.291 | 0.562 | 0.656 | 1.000 | 0.800 | 0.700 | 0.425 | 0.700 | 0.300 | 0.466 |
| 1892-3 | 0.625 | 0.250 | 0.675 | 0.225 | 0.500 | 0.350 | 1.625 | 0.950 | 1.000 | 0.500 | 0.650 | 0.535 | — |
| 1893-4 | 0.550 | 0.200 | 0.233 | 0.250 | 0.350 | 0.375 | 0.213 | 0.625 | 0.458 | 0.625 | 0.400 | 0.583 | 0.381 |
| 1894-5 | 0.625 | 0.300 | 0.150 | 0.325 | 0.300 | 0.958 | 0.500 | 0.575 | 1.167 | 1.437 | 0.225 | 0.357 | 0.364 |
| 1895-6 | 0.700 | 0.325 | 0.287 | 0.350 | 0.650 | 0.950 | 0.350 | 0.800 | 0.675 | 0.900 | 0.675 | 0.484 | — |
| 1896-7 | 0.225 | 0.250 | 0.350 | 0.275 | 0.400 | 0.375 | 0.233 | 0.383 | 0.625 | 0.525 | 1.375 | 0.525 | 0.350 |
| 1897-8 | 0.400 | 0.688 | 0.813 | 0.225 | 0.781 | 0.525 | 0.475 | 0.600 | 0.640 | 0.529 | 0.600 | 0.550 | 0.516 |
| 1898-9 | 1.350 | 0.575 | 0.475 | 0.288 | 0.225 | 0.338 | 0.950 | 0.525 | 0.350 | 0.313 | 0.475 | 0.781 | 0.443 |
| 1899-1900 | 0.500 | 0.275 | 0.525 | 0.900 | 0.263 | 0.250 | 0.550 | 0.700 | 0.650 | 0.333 | 0.950 | 0.400 | 0.431 |
| 1900-1 | 0.800 | 0.288 | 0.625 | 0.675 | 0.575 | 0.400 | 0.275 | 0.263 | 0.375 | 0.575 | 0.750 | 0.525 | 0.498 |
| 1901-2 | 0.625 | 0.625 | 0.550 | 0.225 | 0.383 | 0.867 | 0.475 | 1.500 | 0.625 | 0.550 | 0.575 | 0.675 | 0.571 |
| 1902-3 | 1.500 | 0.525 | 0.675 | 0.475 | 0.400 | 0.500 | 0.812 | 0.450 | 0.541 | 0.417 | 0.275 | 0.313 | 0.447 |
| 1903-4 | 0.500 | 0.263 | 0.325 | 0.600 | 0.375 | 0.300 | 0.675 | 0.625 | 0.625 | 0.750 | 0.417 | 0.600 | 0.424 |
| 1904-5 | 0.719 | 0.475 | 0.313 | 0.400 | 0.263 | 0.600 | 0.250 | 0.750 | 0.900 | 0.350 | 0.821 | 0.350 | 0.460 |

APPENDIX—TABLE IV.

NITROGEN AS NITRATES IN RAIN-WATER COLLECTED AT ROTHAMSTED
IN PARTS PER MILLION.

| | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | March | April | May | June | July | Aug. | Year |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1854-5 | — | — | — | — | 0·06 | 0·16 | 0·08 | 0·13 | 0·13 | 0·30 | 0·06 | 0·22 | — |
| 1855-6 | 0·08 | 0·13 | 0·07 | 0·06 | 0·09 | 0·07 | 0·13 | 0·07 | 0·10 | 0·17 | 0·13 | 0·15 | 0·10 |
| 1856-7 | 0·13 | 0·12 | 0·16 | 0·15 | — | — | — | — | — | — | — | — | — |
| 1886-7 | 0·270 | 0·089 | 0·064 | 0·048 | 0·172 | — | 0·247 | 0·106 | 0·162 | 0·284 | 0·204 | 0·385 | 0·138 |
| 1887-8 | 0·093 | 0·090 | 0·093 | 0·066 | 0·198 | 0·229 | 0·095 | 0·145 | 0·109 | 0·167 | 0·104 | 0·090 | 0·116 |
| 1888-9 | 0·253 | 0·173 | 0·096 | 0·155 | 0·190 | 0·095 | 0·136 | 0·230 | 0·100 | 0·184 | 0·120 | 0·096 | 0·134 |
| 1889-90 | 0·150 | 0·083 | 0·180 | 0·127 | 0·097 | 0·220 | 0·093 | 0·220 | 0·185 | 0·104 | 0·083 | 0·123 | 0·119 |
| 1890-1 | 0·330 | 0·213 | 0·120 | 0·773 | 0·120 | 2·160 | 0·200 | 0·200 | 0·130 | 0·246 | 0·200 | 0·140 | 0·195 |
| 1891-2 | 0·240 | 0·192 | 0·213 | 0·080 | 0·213 | 0·240 | 0·306 | 0·300 | 0·213 | 0·160 | 0·200 | 0·147 | 0·185 |
| 1892-3 | 0·187 | 0·190 | 0·420 | 0·093 | 0·288 | 0·147 | 0·640 | — | 0·347 | 0·340 | 0·173 | 0·187 | 0·217 |
| 1893-4 | 0·160 | 0·083 | 0·090 | 0·090 | 0·114 | 0·150 | 0·093 | 0·240 | 0·173 | 0·147 | 0·160 | 0·160 | 0·131 |
| 1894-5 | 0·267 | 0·198 | 0·072 | 0·140 | 0·083 | 0·667 | 0·420 | 0·260 | 0·500 | 0·380 | 0·100 | 0·120 | 0·461 |
| 1895-6 | 0·320 | 0·200 | 0·142 | 0·222 | 0·260 | 0·420 | 0·170 | — | 0·540 | 0·220 | 0·240 | 0·267 | 0·216 |
| 1896-7 | 0·090 | 0·080 | 0·170 | 0·200 | 0·130 | 0·290 | 0·210 | 0·147 | 0·187 | 0·173 | 0·460 | 0·150 | 0·160 |
| 1897-8 | 0·166 | 0·286 | 0·293 | 0·120 | 0·300 | 0·173 | 0·333 | 0·320 | 0·270 | 0·200 | 0·293 | 0·320 | 0·234 |
| 1898-9 | 0·720 | 0·240 | 0·251 | 0·120 | 0·130 | 0·150 | 0·427 | 0·227 | 0·180 | 0·285 | 0·267 | 0·460 | 0·228 |
| 1899-1900 | 0·227 | 0·190 | 0·200 | 0·620 | 0·160 | 0·150 | 0·290 | 0·213 | 0·240 | 0·093 | 0·360 | 0·128 | 0·200 |
| 1900-1 | 0·560 | 0·200 | 0·187 | 0·220 | 0·293 | 0·320 | 0·187 | 0·160 | 0·280 | 0·320 | 0·347 | 0·267 | 0·250 |
| 1901-2 | 0·267 | 0·261 | 0·270 | 0·200 | 0·160 | 0·336 | 0·176 | 0·320 | 0·206 | 0·500 | 0·274 | 0·200 | 0·267 |
| 1902-3 | 0·560 | 0·272 | 0·304 | 0·375 | 0·225 | 0·300 | 0·125 | 0·250 | 0·180 | 0·168 | 0·116 | 0·135 | 0·203 |
| 1903-4 | 0·183 | 0·133 | 0·263 | 0·288 | 0·213 | 0·133 | 0·213 | 0·313 | 0·450 | 0·317 | 0·175 | 0·275 | 0·214 |
| 1904-5 | 0·325 | 0·325 | 0·213 | 0·142 | 0·133 | 0·250 | 0·125 | 0·225 | 0·375 | 0·125 | 0·313 | 0·163 | 0·197 |

APPENDIX—TABLE V.

CHLORINE IN RAIN-WATER COLLECTED AT ROTHAMSTED
IN PARTS PER MILLION.

| | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Year |
|-----------|-------|------|------|------|-------|-------|-------|-------|------|------|------|------|------|
| 1876-7 | — | — | — | — | — | — | — | — | — | 1.95 | 0.24 | 0.95 | — |
| 1877-8 | 1.73 | 3.40 | 1.97 | 1.96 | 2.91 | 0.50 | 4.00 | 0.55 | 0.91 | 1.48 | 4.31 | 1.16 | 1.62 |
| 1878-9 | 2.28 | 2.58 | 1.83 | 3.00 | 3.04 | 1.83 | 5.80 | 1.67 | 1.40 | 0.80 | 0.80 | 0.85 | 1.69 |
| 1879-80 | 1.05 | 2.65 | 9.38 | 5.75 | 3.20 | 3.20 | 2.90 | 1.73 | 3.43 | 2.47 | 0.64 | 1.30 | 2.25 |
| 1880-1 | 0.97 | 3.00 | 2.95 | 1.70 | 10.00 | 3.45 | 1.95 | 3.20 | 2.88 | 1.63 | 0.67 | 0.53 | 2.17 |
| 1881-2 | 0.75 | 4.20 | 2.70 | 1.80 | 1.70 | 2.50 | 3.75 | 2.60 | 1.60 | 0.80 | 1.60 | 1.68 | 2.13 |
| 1882-3 | 1.15 | 2.28 | 4.30 | 1.60 | 3.00 | 2.25 | 8.85 | 1.60 | 1.40 | 1.12 | 0.73 | 2.00 | 2.23 |
| 1883-4 | 1.90 | 2.50 | 2.30 | 8.80 | 3.60 | 5.75 | 1.65 | 1.65 | 3.70 | 0.80 | 0.62 | 0.90 | 2.43 |
| 1884-5 | 0.85 | 2.25 | 3.33 | 3.80 | 3.42 | 2.75 | 2.35 | 1.45 | 1.50 | 0.75 | 1.45 | 2.27 | 2.20 |
| 1885-6 | 1.00 | 1.90 | 1.57 | 3.43 | 2.58 | 2.25 | 3.60 | 2.77 | 0.93 | 0.98 | 0.50 | 1.45 | 1.73 |
| 1886-7 | 2.10 | 2.95 | 1.65 | 4.63 | 2.28 | 3.50 | 3.28 | 4.75 | 2.15 | 2.00 | 2.90 | 2.70 | 2.99 |
| 1887-8 | 2.70 | 3.35 | 2.95 | 2.73 | 4.90 | 11.05 | 3.40 | 2.20 | 2.50 | 0.75 | 1.33 | 1.03 | 2.46 |
| 1888-9 | 2.30 | 2.15 | 2.37 | 3.43 | 3.05 | 3.90 | 2.25 | 2.55 | 0.40 | 2.17 | 0.77 | 1.42 | 1.85 |
| 1889-90 | 1.30 | 1.83 | 2.10 | 2.10 | 3.05 | 3.95 | 1.60 | 2.93 | 1.15 | 1.15 | 0.43 | 1.20 | 1.66 |
| 1890-1 | 1.90 | 2.00 | 1.95 | 8.05 | 2.50 | 7.50 | 3.50 | 2.50 | 1.30 | 1.25 | 1.45 | 1.20 | 1.99 |
| 1891-2 | 2.00 | 2.71 | 2.75 | 2.75 | 4.08 | 3.45 | 4.20 | 2.60 | 2.40 | 1.20 | 1.00 | 1.13 | 2.31 |
| 1892-3 | 1.95 | 1.75 | 1.82 | 1.08 | 3.20 | 2.85 | 4.95 | — | 2.15 | 2.32 | 1.30 | 1.25 | 2.05 |
| 1893-4 | 3.04 | 1.68 | 4.44 | 6.80 | 4.62 | 2.95 | 2.87 | 2.05 | 2.50 | 1.20 | 1.00 | 0.50 | 2.71 |
| 1894-5 | 1.90 | 2.25 | 2.10 | 4.06 | 4.90 | 4.02 | 3.38 | 1.44 | 2.80 | 3.00 | 1.00 | 1.20 | 2.25 |
| 1895-6 | 1.40 | 2.04 | 2.80 | 4.20 | 3.18 | 3.66 | 2.22 | — | 4.10 | 1.89 | 1.94 | 1.13 | 2.42 |
| 1896-7 | 1.25 | 2.52 | 3.39 | 2.28 | 8.61 | 1.82 | 3.48 | 2.94 | 2.10 | 1.55 | 3.92 | 1.74 | 2.51 |
| 1897-8 | 1.70 | 4.20 | 4.98 | 3.81 | 3.59 | 4.47 | 20.10 | 2.30 | 2.25 | 2.04 | 1.25 | 1.88 | 3.74 |
| 1898-9 | 5.63 | 2.51 | 2.85 | 2.78 | 5.83 | 4.80 | 5.33 | 2.42 | 2.40 | 1.50 | 1.37 | 2.55 | 3.24 |
| 1899-1900 | 2.22 | 1.67 | 2.75 | 4.70 | 2.22 | 1.88 | 5.93 | 3.63 | 2.25 | 1.96 | 2.09 | 1.28 | 2.25 |
| 1900-1 | 3.69 | 2.34 | 3.83 | 3.45 | 7.13 | 3.96 | 1.43 | 2.70 | 5.03 | 2.90 | 1.40 | 1.43 | 3.02 |
| 1901-2 | 2.43 | 4.44 | 5.49 | 2.85 | 3.00 | 6.38 | 2.04 | 3.80 | 3.08 | 1.35 | 1.83 | 1.53 | 2.81 |
| 1902-3 | 3.05 | 3.56 | 4.58 | 5.49 | 4.02 | 5.48 | 5.00 | 3.90 | 1.74 | 1.02 | 0.80 | 1.68 | 2.52 |
| 1903-4 | 1.95 | 2.07 | 2.42 | 5.01 | 3.15 | 4.65 | 4.62 | 3.18 | 2.45 | 2.65 | 0.81 | 1.77 | 2.76 |
| 1904-5 | 1.98 | 2.25 | 1.92 | 2.33 | 3.14 | 11.60 | 3.68 | 3.54 | 2.90 | 1.49 | 0.94 | 1.50 | 2.66 |

THE HYGROSCOPIC CAPACITY OF SOILS.

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THE present communication is intended as a contribution to the study of the capacity of soils to retain moisture in equilibrium with the atmosphere. The experimental material with which it deals consists in part of the analytical data obtained in the investigation of one hundred soils of the county of Dorset, which has been carried out for the County Council, and in part of a series of determinations made for the purpose of elucidating this problem.

All the results refer to fine earth passing through a sieve with round holes 3 mm. in diameter, and the experiments were all made under laboratory conditions, so that no account is taken of the influence of tilth, nor of the stones and gravel with which the fine earth is associated. It is hoped that these drawbacks will be partially removed by a further series of determinations which are contemplated.

The hygroscopic property of soils is due to a variety of causes, which may be roughly grouped under four heads:

1. The proportion and character of the organic material in the soil.
2. The size of the mineral particles, or rather the proportion in which particles of different sizes are present.
3. The chemical and physical nature of the mineral constituents.
4. The temperature, and the humidity of the atmosphere.

It is intended first to deal with the bearing of the analytical data of the Dorset soils on the influence of the first three of these factors, and then to adduce the results of the special experiments showing the hygroscopic capacity of soil particles under varying atmospheric conditions.

INFLUENCE OF ORGANIC MATERIAL.

One of the most potent factors in enabling the soil to retain moisture is known to be the organic material it contains. The relation between the content of organic matter and the content of water is shown in Tables 1 and 2. In these tables the Dorset soils are arranged in four groups according to their loss on ignition, and the maximum, minimum, and mean percentage of moisture is given for each group. The loss on ignition is exclusive of carbon dioxide, but includes combined water.

TABLE 1.

| Number of Soils | Loss on Ignition, per cent. | | | Water in Air-dry, per cent. | | |
|-----------------|-----------------------------|---------|------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 24 | 21.5 | 10.4 | 12.9 | 6.5 | 2.2 | 4.6 |
| 25 | 9.7 | 8.0 | 8.7 | 5.9 | 2.0 | 3.1 |
| 23 | 7.9 | 6.0 | 7.0 | 4.4 | 1.2 | 2.8 |
| 28 | 5.9 | 2.9 | 4.9 | 3.2 | .6 | 1.7 |

TABLE 2.

| Number of Soils | Loss on Ignition, per cent. | | | Water in Air-dry, per cent. | | |
|-----------------|-----------------------------|---------|------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 8 | 21.5 | 13.3 | 15.6 | 6.5 | 4.5 | 5.6 |
| 44 | 12.8 | 7.9 | 9.7 | 5.9 | 2.0 | 3.4 |
| 39 | 7.8 | 4.8 | 6.1 | 4.4 | 1.0 | 2.4 |
| 9 | 4.7 | 2.9 | 4.1 | 1.9 | .6 | 1.3 |

The hygroscopic capacity of a soil is not of course a simple function of its percentage of organic material. Soils differ much in the proportion that exists between the loss they suffer on ignition and their content of moisture, nor is this difference wholly to be explained by the influence of other factors. But to obtain in the first place a numerical expression for the relation which obtains between these and similar quantities, generally, in spite of many individual irregularities, the coefficient of correlation has been calculated from the analytical data of the Dorset soils. This factor has been much used lately in other branches of science, and seems likely to afford useful information in the present enquiry. The coefficient of correlation is a number which varies in different cases through all values from +1 which connotes

complete interdependence of two measurable quantities through fractional values representing degrees of positive correlation down to zero for unconnected quantities, and then through negative fractions to -1 for perfect correlation in an inverse sense¹. In this paper it will be expressed by such symbols as $R_{100} \left(\frac{\text{moisture}}{\text{loss on ignition}} \right) = .83$. This indicates that the coefficient of these quantities calculated from the data of 100 soils has the value given. The second place of decimals is usually given, but is of doubtful significance.

That the hygroscopic power of the organic material is chiefly due to non-nitrogenous constituents is no doubt a general opinion, and seems to be confirmed by the following figures :

$$R_{100} \left(\frac{\text{moisture}}{\text{nitrogen}} \right) = .74, \quad R_{100} \left(\frac{\text{nitrogen}}{\text{loss on ignition}} \right) = .91.$$

The connexion between moisture and nitrogen is probably only indirect; the correlation between the other pairs of the three quantities is high and is no doubt causal; there would thus of necessity be a correlation between moisture and nitrogen, though they had absolutely no direct connexion as cause and effect.

FINENESS OF THE SOIL.

The dependence of the hygroscopic power of the soil on the fineness of its particles is well known. Further on an attempt is made to give this some definite numerical expression. To obtain a factor of correlation from the mechanical analysis of the soils one has to choose a single figure to express the fineness of each soil, and this is a matter of some difficulty. The soil is mechanically divided into six or seven fractions containing particles of various grades varying in diameter from about 2 millimetres down to less than 2μ . An obvious figure to take is the ratio between particles above and below a definite size, or, what comes to the same thing, the percentage of material below a certain limit. Taking this limit at 10μ we get $R_{82} \left(\frac{\text{moisture}}{\text{fine material}} \right) = .66$. By raising the limit to 40μ or lowering it to 4μ the coefficient is reduced to .56 and .54. If again there is taken as a measure of fineness the percentage under 2μ

¹ Convenient methods for calculating the coefficient of correlation are given on pages 64-72 of "The Measurements of Groups and Series," by my colleague Mr A. L. Bowley, M.A., F.R.S.

(clay) plus fractions of the percentage of the next two coarser grades ($\cdot 4[2\mu \text{ to } 4\mu] + \cdot 16[4\mu \text{ to } 10\mu]$) the coefficient works out to $\cdot 53$.

Only 82 soils are used for these calculations, namely those containing less than 7 per cent. of calcium carbonate. The figures used as a measure of fineness include the organic as well as the mineral particles except that the humus soluble in aqueous ammonia is removed. In Table 3 the soils are grouped into four sets according to the ratio of coarse material to fine, the line of demarcation being taken at or about 10μ . The moisture is readily seen to vary inversely as the ratio of the coarse particles to the fine.

TABLE 3.

| Number of Soils | Ratio of Coarse to Fine Material | | | Water in Air-dry, per cent. | | |
|-----------------|----------------------------------|---------|---------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 16 | 50 : 50 | 25 : 75 | 40 : 60 | 6.5 | 2.1 | 4.3 |
| 24 | 65 : 35 | 48 : 52 | 60 : 40 | 6.0 | 1.5 | 3.2 |
| 26 | 77 : 23 | 66 : 34 | 72 : 28 | 5.0 | 1.4 | 2.6 |
| 16 | 91 : 9 | 78 : 22 | 84 : 16 | 3.0 | .6 | 1.5 |

NATURE OF THE MINERAL CONSTITUENTS.

The first indication of the chemical and physical nature of the mineral constituents that falls to be considered is the total percentage brought into solution by digestion with hot concentrated hydrochloric acid. It is necessary, however, either to confine attention to soils with only a moderate amount of calcium carbonate, or to subtract this constituent from the total minerals before attempting to calculate a correlation coefficient. Of the Dorset soils 18 contain a percentage varying from 7.0 to 9.0, whilst the remaining 82 contain from 7.0 down to 0.3 per cent. of calcium carbonate. The following results have been obtained:

$$R_{82} \left(\frac{\text{moisture}}{\text{total soluble minerals}} \right) = .72, \quad R_{100} \left(\frac{\text{moisture}}{\text{soluble minerals} - \text{CaCO}_3} \right) = .74,$$

$$R_{100} \left(\frac{\text{moisture}}{\text{CaCO}_3} \right) = 0 \text{ (nearly).}$$

The zero value of the last coefficient is not adduced to show that calcium carbonate has no hygroscopic property, but with the close agreement between the two factors for moisture and soluble minerals it fully justifies the method of calculation.

Table 4 gives the 82 soils divided into four groups according to their percentage of soluble minerals, and illustrates the dependence of moisture on this factor. It is seen how the mean water content of each group varies with its mean percentage of mineral constituents soluble in hot concentrated hydrochloric acid. But as in the other tables, the relation is far less manifest in the maxima and minima because here individual differences make themselves evident, and the influence of other factors comes into play.

TABLE 4.

| Number of Soils | Soluble Minerals, per cent. | | | Water in Air-dry, per cent. | | |
|-----------------|-----------------------------|---------|------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 16 | 26.9 | 18.0 | 21.3 | 6.5 | 3.2 | 4.7 |
| 23 | 17.6 | 13.0 | 15.2 | 6.0 | 2.1 | 3.2 |
| 25 | 12.2 | 8.2 | 10.2 | 6.0 | 1.0 | 2.6 |
| 18 | 8.0 | 1.7 | 5.7 | 3.0 | .6 | 1.5 |

The high correlation between moisture and soluble mineral constituents is rather surprising, especially as it seems to show a greater dependence on this factor than on the fineness of the soil. This may be partly due to the difficulty of expressing the fineness of the soil by a single number suitable for the calculation, and it is certainly partly the result of the physical condition of the finer particles in the laboratory samples, for the clay is unable to exert its full hygroscopic influence.

But even irrespective of comparison with the factor obtained from the results of mechanical analysis, the high figure obtained for the correlation of moisture with soluble minerals deserves consideration. The question arises whether the influence of the soluble minerals is due to their chemical nature being different from that of the insoluble residue, or whether their hygroscopic power and their susceptibility to the attack of hot acid are only indirectly connected as the results of a common cause to be found in their physical condition both as to fineness and in other ways.

For the purpose of elucidating this problem the coefficient of correlation was calculated in the first place for moisture with each of the several constituents dissolved, and the following results were obtained:

$$R_{100} \left(\frac{\text{H}_2\text{O}}{\text{P}_2\text{O}_5} \right) = \cdot 25, \quad R_{100} \left(\frac{\text{H}_2\text{O}}{\text{SO}_3} \right) = \cdot 49, \quad R_{100} \left(\frac{\text{H}_2\text{O}}{\text{K}_2\text{O}} \right) = \cdot 44,$$

$$R_{100} \left(\frac{\text{H}_2\text{O}}{\text{Na}_2\text{O}} \right) = \cdot 24, \quad R_{100} \left(\frac{\text{H}_2\text{O}}{\text{MgO}} \right) = \cdot 36,$$

$$R_{100} \left(\frac{\text{H}_2\text{O}}{\text{Al}_2\text{O}_3} \right) = \cdot 58, \quad R_{100} \left(\frac{\text{H}_2\text{O}}{\text{Fe}_2\text{O}_3} \right) = \cdot 64.$$

If the high water content of soils with high percentage of minerals soluble in acid is due to the soluble materials being in a fine condition, and therefore both readily attacked by acid on the one hand and with a large surface attraction for moisture on the other hand, we should expect the alumina to give us a good measure of the property, as it is the principal base in soluble silicates, and is little affected by manuring and cropping. The actual figure of $\cdot 6$ obtained is only a little below $\cdot 7$, which represents the correlation with total minerals, whilst all the other constituents except iron oxide give lower figures. The phosphorus pentoxide of course is very low, the potash is higher perhaps because the soils generally being rich in this constituent the influence of cropping is less than it would be in other soils. Before drawing conclusions from these figures even tentatively, it should be mentioned that possibly a partial cause for the high correlation between water and soluble minerals may be found in an effect of the organic substance in rendering the minerals soluble.

$$R_{100} \left(\frac{\text{loss on ignition}}{\text{soluble minerals} - \text{CaCO}_3} \right) = \cdot 60.$$

Here again, however, it is difficult to be sure of the cause, as the soluble minerals would probably raise the combined water which is included in the loss on ignition.

TABLE 5.

| Number of Soils | Iron Oxide, per cent. | | | Water in Air-dry, per cent. | | |
|-----------------|-----------------------|---------|------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 14 | 14.7 | 6.8 | 9.0 | 6.0 | 3.1 | 4.4 |
| 26 | 6.6 | 4.6 | 5.7 | 6.5 | 2.0 | 3.8 |
| 47 | 4.5 | 2.4 | 3.4 | 6.0 | 1.0 | 2.5 |
| 13 | 2.2 | .4 | 1.4 | 2.8 | .6 | 1.9 |

It remains to consider the high figure obtained for iron oxide. It seems probable that this indicates a definite causal relation between the

presence of iron oxide and the hygroscopic capacity of the soil. The relation is shown in Table 5 similarly to that in other cases.

It would seem a reasonable hypothesis that the mineral constituents of the soil having a notable hygroscopic effect may be divided into three groups, namely:

A. Silicates and silica in fine particles, the silicates not decomposable by hot concentrated hydrochloric acid. This material owes its hygroscopic influence entirely to surface attraction for water.

B. Silicates decomposable by the hot acid used. This material is probably to a large extent in a condition of sufficient fineness to give it considerable power of surface attraction. The base present in largest and most regular quantity is likely to be alumina, the percentage of which dissolved by the acid may therefore be taken as a measure of the amount of this material.

C. Iron oxide and its compounds having a specific attraction for moisture that may perhaps be correlated with the possibility of formation of loosely combined chemical hydrates.

On this hypothesis the influence of groups *A* and *B* would be found in the coefficient obtained from the mechanical analysis results, whilst that of *C* would of course be measured by the factor $R \left(\frac{\text{moisture}}{\text{iron oxide}} \right)$ already given.

But if this hypothesis be correct, the factor obtained for alumina and iron oxide should not differ much from that for total soluble minerals, the other constituents being regarded as negligible. In point of fact

$$R_{100} \left(\frac{\text{H}_2\text{O}}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} \right) = \cdot 71,$$

which agrees well with the other factor $\cdot 72$ or $\cdot 74$.

The dependence of the moisture in the soil on the organic material and on the soluble minerals severally suggests that the correlation would be still closer with their sum, and, as the total weight of the fine earth is made up of the four parts—water, loss on ignition, soluble minerals, and insoluble residue—this is the same thing as saying that there will be close correlation in the inverse sense between water and insoluble mineral substance.

$$R_{22} \left(\frac{\text{moisture}}{\text{insoluble minerals}} \right) = -\cdot 9 \text{ or } -\cdot 88$$

(according to the method of calculation).

The relation is clearly shown in Table

TABLE 6.

| Number of Soils | Insoluble Minerals, per cent. | | | Water in Air-dry, per cent. | | |
|-----------------|-------------------------------|---------|------|-----------------------------|---------|------|
| | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
| 11 | 64 | 56 | 60 | 6.5 | 4.1 | 5.3 |
| 30 | 76 | 66 | 72 | 5.0 | 2.0 | 3.3 |
| 31 | 87 | 77 | 82 | 3.6 | 1.0 | 2.2 |
| 10 | 95 | 88 | 90 | 1.9 | .6 | 1.2 |

COMPOSITION OF THE SOILS.

For the sake of giving a general idea of the character of the soils on which the above results are based, there are given in Table 7 the mean percentages of some of the principal constituents, with in many cases the standard deviation from the mean¹. Some of these figures are taken from the whole of the 100 soils and some only from the 82 which contain less than 7 per cent. of calcium carbonate, so that the data do not give the exact analysis of even an imaginary soil, but rather serve to indicate the range of values which have been used in the calculations.

TABLE 7.

| | per cent. |
|---|-------------|
| Water lost at 95° C. (100)... | 8.0 ± 1.3 |
| Organic Substance and Combined Water | 8.3 ± 3.2 |
| Containing Nitrogen..... .. | .26 ± .13 |
| Insoluble Mineral Substance (82) ... | 76.5 ± 9.3 |
| Soluble Mineral Constituents | 12.6 ± 5.5 |
| Phosphoric acid anhydride (100)... | .37 ± .14 |
| Sulphuric acid anhydride | .25 ± .13 |
| Potash..... .. | .41 ± .21 |
| Soda..... .. | .31 ± .17 |
| Carbonate of Lime | 70.0 to .03 |
| Magnesia | .40 ± .24 |
| Iron Oxide | 4.5 ± 2.5 |
| Alumina | 4.5 ± 2.5 |

EXPERIMENTS WITH SOIL PARTICLES.

The experiments which now come to be described were carried out with a view to determining the relative hygroscopic power of mineral

¹ Standard deviation or deviation of mean square

$$= \left(\frac{\delta_1^2 + \delta_2^2 + \dots + \delta_n^2}{n} \right)^{\frac{1}{2}}$$

soil particles of different sizes, and ascertaining how far this property may be regarded as proportional to the probable area of the surface they offer to the atmosphere.

Seven different soils have been used altogether, and in addition some coarse sand, extracted with strong hydrochloric acid and ignited, was ground down under water to give a kind of artificial soil free from organic matter and soluble mineral constituents. The ground sand and the soils were separated by sifting and elutriation into six fractions, of which the approximate mean diameters were found to be as follows, expressed in thousandths of a millimetre:

I, 300; II, 80; III, 24; IV, 8; V, 3; VI, 1½.

FIRST SERIES OF EXPERIMENTS.

In the first series of experiments a number of small weighing bottles were prepared, containing respectively a gram each of five different soils and of their six fractions. These were put under a bell-jar, together with a dish which contained during most of the experiments a solution of calcium chloride of which the concentration was determined when the bottles were removed for weighing; at the conclusion of the series the dish was filled with granular calcium chloride in order to obtain the weight of the samples in equilibrium with a dry atmosphere. The water lost at 95° and the loss on ignition were also found, but all results are calculated to the weight of the material dried in this manner in the cold.

In Table 8 the results of this series are given so as to show their bearing on the question of surface action. There were not an adequate number of observations under sensibly equal atmospheric conditions to eliminate accidental variations, and to give one confidence in the results for each soil-fraction separately; the figures are therefore grouped so that under I for example is given the mean gain of moisture of each of the five soil-fractions of this grade, and similarly for II, III, IV, V, VI. So, too, the percentage loss on ignition treated as organic matter is calculated for the mixed material of the five soils.

The gain of weight is given in Table 8 for each of five different atmospheric conditions. In the so-called normal atmosphere, standing over approximately $\text{CaCl}_2, 9\text{H}_2\text{O}$, the soils and fractions had much the same weight as in what is usually called the air-dry condition. The succeeding lines give figures for atmospheres of increasing moistness.

TABLE 8.

| Fractions..... | I | II | III | IV | V | VI |
|--|------|------|------|------|------|-------|
| Mean diameter in mikrons ... | 300 | 80 | 24 | 8 | 3 | 1½ |
| Organic matter per cent. | 16.6 | 5.5 | 10.5 | 15.9 | 20.4 | 29.6 |
| Moisture absorbed per cent.: | | | | | | |
| 9. Normal atmosphere ... | 1.02 | .43 | .84 | 1.39 | 1.82 | 2.16 |
| 17. Moist atmosphere | 1.80 | .79 | 1.54 | 2.61 | 3.68 | 5.02 |
| 22. " " | 2.63 | 1.21 | 2.39 | 3.95 | 5.69 | 8.97 |
| 37. " " | 2.82 | 1.30 | 2.54 | 4.09 | 6.32 | 11.78 |
| 74. Very moist atmosphere | 3.63 | 1.68 | 3.33 | 5.45 | 7.83 | 20.17 |
| Mean of all..... | 2.38 | 1.08 | 2.13 | 3.50 | 5.07 | 9.62 |
| Allow for Organic | 2.38 | .79 | 1.50 | 2.27 | 2.91 | 4.23 |
| Due to Surface | — | .29 | .63 | 1.23 | 2.16 | 5.39 |
| Moisture Multiple..... | — | — | 2.2 | 2.0 | 1.8 | 2.5 |
| Mean of 9, 17, 22 | 1.82 | .81 | 1.59 | 2.65 | 3.73 | 5.38 |
| Allow for Organic | 1.82 | .60 | 1.15 | 1.74 | 2.24 | 3.25 |
| Due to Surface | — | .21 | .44 | .91 | 1.49 | 2.13 |
| Moisture Multiple..... | — | — | 2.1 | 2.1 | 1.7 | 1.5 |
| Surface } diameter ⁻¹ | — | — | 3.3 | 3.0 | 2.7 | 2.3 |
| Multiples } diameter ⁻² | — | — | 2.2 | 2.1 | 1.9 | 1.7 |

A comparison of the gains of fraction I with those of fraction II shows the great power that organic matter has of attracting moisture. In the succeeding fractions the percentage of organic matter rises steadily with diminishing dimensions of the particles, and thus the order of magnitude is always increasing as we pass to the right from II towards VI. But to obtain an expression for surface effect it is necessary to eliminate the influence of the organic matter, and this offers a difficulty. We proceed on the basis of two assumptions. Firstly, we suppose that all the organic material is equally hygroscopic, whatever size its particles be, or whatever other differences there may be between the organic matter of the different fractions. Secondly, it is assumed that the hygroscopic power of fraction I is entirely due to its organic matter. Underneath the figures in the table giving the mean gains of each fraction there are set down the amounts that must be allowed for organic matter on the above assumptions. The difference is the value to be attributed to surface attraction. The ratio of the surface effect of each of the four finer fractions to the next coarser is called the moisture multiple, and is given in the next line. The moisture multiples are given for the mean of the three less moist atmospheres as well as for the

mean of the whole series. Whilst all the figures in the tables show a satisfactory general regularity in their increase, the moisture multiples are somewhat irregular. In other words, whilst the figures show that the moisture gained increases alike with increased organic matter and increased moistness of the atmosphere and diminished dimensions of the particles, they do not give very clear information as to the law which connects the increase of moisture with increased fineness of the particles. It should, however, be observed that the irregularity is chiefly connected with the high water content of the finest particles (VI or so-called clay) in the very moist atmosphere. Apart from this the moisture multiples are approximately inversely proportional to the two-thirds power of the diameter.

At the beginning of the experiments fluctuations of temperature were found to be considerable, and, it was feared, rather rapid; and this was the more serious as some of the fractions were somewhat slow in attaining equilibrium with the atmosphere. To reduce fluctuations a large tin jacket containing water was put over the bell-jar, and by the use of a maximum and minimum thermometer inserted in the water a more exact knowledge of the temperature variations was obtained. The temperature was not kept exactly uniform, but the samples were left under the bell-jar for prolonged periods, and only removed for weighing when the temperature variations had been slight during several days. The water-jacket was used during the latter part of the first series of experiments, and during the whole of the series to be presently described.

SECOND SERIES OF EXPERIMENTS.

The first series of experiments showed considerable irregularities in the individual figures obtained, notwithstanding the general agreement shown in Table 8. Some of these might have been due to temperature fluctuations, but they cannot be altogether accounted for in this manner, and some of the variations in weight seem inexplicable. To reduce the effect of these as much as possible the second series of experiments was extended over a greater number of observations, and more duplicates were used. The standard weights attained in a cold, dry atmosphere were determined eight times, five times over granular calcium chloride, and three times over fused caustic potash, and the results obtained were in most cases in satisfactory agreement. Then the results given in Table 10 as the moisture gains in a particular atmosphere are the means of several determinations. The sets of weighings taken at

different times are grouped together, for the purpose of getting a mean result, according to the total gain or loss of the whole set of samples. In this way the differences of temperature at which the soil-fractions and the calcium chloride solutions were in equilibrium exercise no influence on the results. Thus three series of weighings with concentration of solution varying between $\text{CaCl}_2 \cdot 16\text{H}_2\text{O}$ and $\text{CaCl}_2 \cdot 23\text{H}_2\text{O}$ gave an average gain per bottle of .0041, .0061, and .0068; the mean of these weighings is given in the table as "18. Moist atmosphere." The whole series of weighings has been grouped under the six atmospheres given in Table 10. The results given in Table 10 were obtained with two soils; the six fractions of each included altogether eight duplicates, so that each column gives a mean of the results with three or four separate samples. It may be mentioned in passing that the figures in Tables 8—11 are based on altogether nearly 2000 weighings.

Again, in calculating the results of the first series of experiments it was found that the soils themselves held more moisture, and in some cases much more moisture than the quantities calculated from the contents of their respective fractions. This is shown in Table 9, where the five soils are given separately. It will be seen that of the 25 comparisons only five show less moisture found than calculated, and the excess of found over calculated is very considerable in many cases.

TABLE 9.

| Soil number..... | 17 | | 28 | | 29 | | 27 | | 30 | |
|-------------------------|------------|-------|------------|-------|------------|-------|------------|-------|------------|-------|
| | Calculated | Found | Calculated | Found | Calculated | Found | Calculated | Found | Calculated | Found |
| 9. Normal atmosphere | 1.44 | 2.23 | 1.55 | 2.24 | 1.02 | 1.50 | .51 | .81 | .32 | .42 |
| 17. Moist atmosphere... | 2.99 | 3.75 | 2.85 | 3.84 | 2.30 | 2.84 | 1.17 | 1.48 | .69 | .82 |
| 22. " " ... | 4.37 | 5.22 | 4.55 | 5.63 | 3.62 | 4.12 | 1.76 | 2.11 | 1.17 | 1.11 |
| 37. " " ... | 4.80 | 6.13 | 5.23 | 6.44 | 4.01 | 4.36 | 1.88 | 2.33 | 1.31 | 1.01 |
| 74. Very moist " ... | 6.21 | 8.00 | 7.23 | 7.72 | 5.86 | 5.65 | 2.62 | 2.39 | 2.15 | 1.14 |

This is what might be expected if it be borne in mind that in the determination of the moisture capacity of the finer fractions the material is aggregated together in what must be a very unfavourable condition for the exercise of surface action, whilst in the soil itself the coarser particles serve to keep the finer ones apart, and are probably coated over with them. To give the finer material a fairer field for its hygroscopic activity in the second series of experiments the three finer fractions of soil were well mixed up with water and then distributed

over coarse particles of sand over .2 mm. in diameter. Moreover, instead of taking 1 gram for each sample, quantities were taken varying from 2 grams for the coarsest down to as little as .14 gram for the finest particles.

This, however, has introduced a difficulty into the calculations, because, although the hygroscopic power of the finer grades is immensely greater than that of coarse quartz sand, yet the large quantity of this that needed to be taken makes one hesitate to utterly neglect its influence. On the other hand, if the use of the coarse particles is to bear a coating of the finer, it does not seem right to take account of their own natural surface action also. On the whole it has seemed best to give the results without any correction for the action of the sand. But it will be seen that the results for the finer three grades cannot now be compared with that for fraction III.

TABLE 10.

| Fractions..... | I | II | III | IV | V | VI |
|--|-----|-----|------|------|------|-------|
| Mean diameter in mikrons ... | 300 | 80 | 24 | 8 | 3 | 1½ |
| Organic matter per cent. | 1.0 | — | 5.5 | 11.0 | 16.0 | 23.0 |
| Moisture absorbed per cent.: | | | | | | |
| 8. Normal atmosphere ... | .07 | .05 | .20 | .66 | 1.10 | 1.53 |
| 10. " " " " ... | .11 | .09 | .29 | 1.02 | 1.80 | 2.30 |
| 18. Moist atmosphere | .17 | .15 | .59 | 2.10 | 3.40 | 5.83 |
| 33. " " " " ... | .26 | .26 | .99 | 3.32 | 6.16 | 12.04 |
| 64. Very moist atmosphere | .35 | .31 | 1.29 | 4.12 | 7.70 | 17.32 |
| 95. " " " " ... | .37 | .33 | 1.35 | 4.67 | 8.87 | 22.29 |
| Mean of all..... | .22 | .20 | .79 | 2.65 | 4.84 | 10.22 |
| Allow for Organic ... | — | — | .74 | 1.43 | 2.15 | 3.10 |
| Due to Surface | — | — | .05 | 1.17 | 2.69 | 7.12 |
| Moisture Multiple | — | — | — | — | 2.3 | 2.6 |
| Mean of 8, 10, 18 | .12 | .10 | .36 | 1.26 | 2.10 | 3.22 |
| Allow for Organic | — | — | .33 | .66 | .96 | 1.38 |
| Due to Surface | — | — | .03 | .60 | 1.14 | 1.84 |
| Moisture Multiple | — | — | — | — | 1.9 | 1.6 |
| Surface } diameter ⁻¹ | — | — | — | — | 2.7 | 2.3 |
| Multiples } diameter ⁻² | — | — | — | — | 1.9 | 1.7 |

The soils chosen for the second series of experiments contained very little organic substance in the two coarser fractions, and it is not possible in the figures given in Table 10 to calculate the influence of the organic substance from the hygroscopic capacity of fraction I or fraction II. A

provisional assumption has been made according to which nearly all the influence of fraction III is attributed to its organic substance, in order to give ratios for the surface action of the smaller particles. This is a very arbitrary assumption, and the figures of course do not harmonise well with those on Table 8, but on the other hand it seems best to treat each set of figures by themselves in the first place, and moreover it is possible to allow some latitude in the amount of influence ascribed to organic substance without producing a very large effect on the moisture multiples due to surface.

The general aspect of Table 10 suggests that we have here a lower series of figures than in Table 8. This is, however, chiefly due to the lower percentage of organic substance in each fraction, and also in part to a greater weight given in the means of Table 10 to the atmospheres with less moisture. The order of moisture in the two series is roughly as indicated by the numbers. The mean of all in each table will probably be similar; but the mean of 8, 10, 18 represents a much drier atmosphere than 9, 17, 22. It must, however, be confessed that the results are a little disappointing as to the influence of distributing the finer fractions on coarse sand.

EXPERIMENTS WITH GROUND SAND.

In Table 11 are given the results with the ground down sand fragments. Most of the figures obtained are very small; the differences between fractions I, II, III are of the order of experimental error. Fraction IV *a* consisted of 2 gr. in a weighing bottle by itself; it absorbed

TABLE 11.

| Fractions..... | I, II, III | IV <i>a</i> | IV <i>b</i> | V | VI <i>a</i> | VI <i>b</i> |
|------------------------------|------------|-------------|-------------|------|-------------|-------------|
| Mean diameter in mikrons... | — | 8 | 8 | 3 | 1½ | 1 |
| Moisture absorbed per cent.: | | | | | | |
| 8. Normal atmosphere... | ·01 | — | ·06 | ·09 | ·37 | ·81 |
| 10. " " " " " " | ·03 | ·05 | ·17 | ·25 | ·95 | 1·49 |
| 18. " " " " " " | ·04 | ·06 | ·20 | ·29 | 1·76 | 4·26 |
| 33. " " " " " " | ·07 | ·11 | ·51 | ·65 | 4·10 | 11·90 |
| 64. Very moist atmosphere | ·08 | ·16 | ·54 | ·74 | 6·90 | 19·0 |
| 95. " " " " " " | ·10 | ·17 | ·74 | 1·04 | 8·39 | 27·3 |
| Mean of all..... | ·05 | ·09 | ·37 | ·51 | 3·74 | 11·3 |
| Moisture Multiple..... | — | 1·8 | 4·1 | 1·4 | 7·3 | 3·0 |
| Mean of 8, 10, 18..... | ·03 | ·05 | ·14 | ·21 | 1·02 | 2·2 |
| Moisture Multiple..... | — | 1·7 | 2·8 | 1·5 | 4·9 | 2·2 |

very little more water than the coarser grades. Fraction IVb was almost identical material .75 gr. mixed with 5 gr. of coarse sand. If from the figures for this fraction one deducts a proper allowance for the coarse sand, the remainders are approximately equal to the figures for IVa. In column V also the deduction for the 5 gr. coarse sand with which the fraction is mixed would make a great proportional difference; and these figures for fraction V, which are the means of fairly concordant determinations on duplicate specimens, are very low. It will be observed that in making the surface action of fraction III in Table 10 equal to that given on Table 11, we get far higher figures for the surface of mineral fragments in fractions IV and V in Table 10 than the mineral fragments in Table 11 actually give. (See 1 under general conclusions below.)

The fractions VIa and VIb are samples of fine material from the levigation and elutriation of coarse washed sand respectively above and below 2 mm. in diameter. There is a slight difference in dimensions as given, but for the great differences between the two samples there is no adequate reason to assign. No other pair of samples has given such discrepancies. The figures are given in the table because they furnish an extreme example of the way in which the water content of the finest material goes up in very moist atmospheres. The same result in far less degree can be observed in Tables 8 and 10 for fraction VI in the very moist atmospheres. As, however, it is there masked by the organic matter, there is set forth in Table 12 the result of grouping together the results of both series of experiments for fractions IV, V, VI for the very moist atmospheres, and making an allowance for organic substance exactly as it is done in Tables 8, 10. We see then how the moisture multiple V/IV rises to 2.6, and that for VI/V to 3.8, which are far higher figures than are met with elsewhere.

TABLE 12.

| Fractions | IV | V | VI |
|------------------------------------|------|------|-------|
| Mean diameter in mikrons | 8 | 3 | 1½ |
| Organic matter per cent. | 12.6 | 17.5 | 25.2 |
| Moisture absorbed per cent.: | | | |
| 74, 64, 95. Very moist atmospheres | 4.75 | 8.13 | 19.93 |
| Allow for Organic | 3.38 | 4.61 | 6.69 |
| Due to Surface | 1.37 | 3.52 | 13.24 |
| Moisture Multiple | — | 2.6 | 3.8 |

CONCLUSIONS.

The following are the most important general conclusions that can be drawn from the experiments:

1. The organic substance not only has a powerful direct influence in attracting moisture, but it also acts indirectly, so that the joint effect of the organic substance and the surface of the mineral particles is not merely an additive property. The organic material probably serves to keep the finer grades of mineral matter apart and free to exercise surface attraction far more effectually than the coarser mineral particles are able to do.

2. It appears that the organic substance in different fractions has not always the same hygroscopic power. For example, on comparing the figures for fractions I and III in Table 10, it is seen that the moisture absorbed by the latter is never so much as four times that absorbed by the former, although the organic substance is present in more than five times as large a proportion, and it is impossible to believe that the mineral particles of fraction III can exercise less effect than those of fraction I. These results are the same if the figures are taken for the two soils separately or for the mean, as given in Table 10.

3. Mineral particles of the same size in different soils have not identical hygroscopic power. This result, which is in harmony with the results given above (pp. 307—310) based on the coefficients of correlation of the whole of the Dorset soils, is clearly seen in Table 13. In Table 10 the figures given are the mean of experiments with two soils—No. 37, taken from the Gravel, and containing 6.9 per cent. soluble minerals, of which 3.04 is iron oxide; and No. 33, from the Wealden beds, which gives 10.3 per cent. soluble minerals, 3.88 per cent. being iron oxide. No. 37 also contains less organic matter than No. 33, but fractions V and VI of the former contain more organic substance than the corresponding fractions of the latter. The separate results are given in Table 13, where it is seen that, while 33 V contains only about four-fifths of the organic substance contained in 37 V, it absorbs about one-eighth more water in the average of the six atmospheric conditions. The "clay" of 33 (fraction VI) contains only about three-quarters of the organic substance contained in that of 37, but it has about an equal capacity for water. This is evidently due to the greater hygroscopic power of the mineral particles of the more ferruginous soil.

4. The finest grade particles, especially the clay fraction VI, show specially high attraction for water in atmospheres of extreme moistness,

and the moisture multiple VI/V is accordingly a function of the atmospheric moisture. Thus in Table 10 this factor is given as 1.6 for the atmospheres 8, 10, 18. But it rises to 2.9 for the moister atmospheres 33, 64, 95, and, as shown in Table 12, it rises to 3.8 for the very moist atmospheres 64, 76, 95. That this is an effect of the mineral particles is clear from Table 11, for, neglecting the altogether abnormal fraction VI *b*, we get increasingly high moisture multiples in the moist atmospheres for VI *a*/V.

TABLE 13.

| | | | | |
|-------------------------------|------|------|-------|-------|
| Soil number | 37 | 33 | 37 | 33 |
| Fraction | V | V | VI | VI |
| Organic matter per cent. | 17.5 | 14.1 | 26.4 | 19.7 |
| Moisture absorbed per cent.: | | | | |
| 8. Normal atmosphere ... | 1.05 | 1.15 | 1.30 | 1.73 |
| 10. " " " " | 1.68 | 1.92 | 1.80 | 2.63 |
| 18. Moist atmosphere | 3.27 | 3.54 | 5.51 | 5.92 |
| 33. " " " " | 5.60 | 6.72 | 12.18 | 12.00 |
| 64. Very moist atmosphere | 7.48 | 7.88 | 17.31 | 17.32 |
| 95. " " " " | 8.03 | 9.59 | 22.85 | 22.06 |
| Mean of all..... | 4.52 | 5.13 | 10.16 | 10.28 |

5. It follows from the foregoing that the attraction of mineral particles for moisture cannot be strictly expressed as simply proportional to their surface, and it is readily seen that many apparent irregularities in the tables are due to the causes operating in accordance with 1, 2, 3, 4 above. But within certain limits as to moisture in the atmosphere, and in spite of the disturbing influence of other factors such as the varying attraction of the organic material, its indirect action, and the special hygroscopic action of iron oxide and perhaps other soluble minerals, there is a regularity in what is here called the moisture multiple, so that it tends to assume a value inversely proportional to the diameter raised to the two-thirds power:

$$\text{moisture multiple} = (\text{diameter multiple})^{-\frac{2}{3}}.$$

This does not at first seem like a surface ratio. It is a well-known mathematical fact that similar solids have surfaces varying as the square, and volumes as the cube of their linear dimensions. Treating the density as a constant, this leads to the well-known proposition that a gram say of material of uniform size and shape will have its total

surface increased twofold if, the shape remaining the same, the linear dimensions of each particle are halved; we get eight times as many particles, each having a quarter of the surface of the large, and therefore the total surface $8 \div 4 = 2$.

But it is not difficult to convince oneself that there is a considerable probability that, if the smaller particles are derived from the larger by fracture and attrition, they will on the whole be shaped so as to offer less surface than if they were reduced images of the coarser ones. It is also the writer's impression, from observation when measuring the particles, that the smaller ones are apt to have the two dimensions that are at right angles to the axis of the microscope more nearly equal than in the case of the larger pieces.

However this may be, it appears as if the use of the two-thirds power ratio was most suitable for the majority of cases, but in the case of the finest particles in a very moist atmosphere the increase in moisture gained proceeds at a far higher rate.

A METHOD FOR THE DETERMINATION OF CARBONATES IN SOILS.

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THE methods usually employed for estimating calcium carbonate in soil are all subject to more or less serious practical difficulties when the percentage of lime falls below 0.5.

In gravimetric methods, in which the carbon dioxide set free by acid has first to be boiled out of solution and then perfectly dried before absorption by potash, a very small weight of carbon dioxide is estimated by the gain in weight of a comparatively heavy absorption apparatus.

The volumetric method of Scheibler also cannot be used for soil containing only 0.5 per cent. of lime because all the carbon dioxide remains in solution in the decomposing acid.

The method devised by Hall and Russell¹ (in which the lime is decomposed in an exhausted apparatus, and the carbon dioxide set free calculated from three readings of pressure, taken (1) before the addition of acid, (2) on equilibrium being established after the acid is added, (3) on equilibrium being established when the gas is allowed to expand into a further exhausted and known volume) gives very accurate results; but much shaking is required in order to overcome the supersaturation of the decomposing acid with the carbon dioxide, and hence each determination occupies a considerable time, and leakages are apt to occur unless the taps are very perfect.

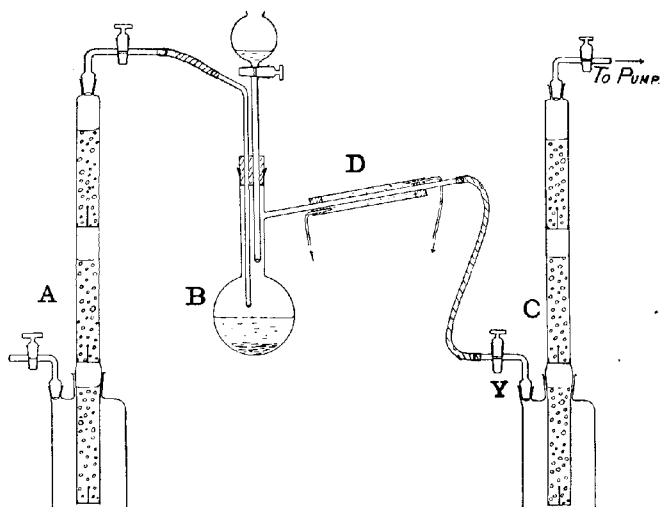
Brown and Escombe² in the course of their work on carbon assimilation of plants have shown that, by a modification of Hart's method of double titration for estimating sodium carbonate in the presence of

¹ *Trans. Chem. Soc.* 1902, Vol. LXXXI. p. 81.

² *Phil. Trans. Roy. Soc.* 1900, Vol. CXCIII. pp. 289—291.

sodium hydrate, quantities of carbon dioxide, varying from 1 to 100 c.c. and contained in 100 c.c. of 4 per cent. sodium hydrate solution, can be determined within 2 c.c. of the quantity added.

Whilst making use of this method for determining the varying amounts of carbon dioxide in the atmosphere it was suggested to me by Mr A. D. Hall, M.A., that a modification of this might be employed for determining calcium carbonate in soil, which led to the following method being devised.



The apparatus as shown in the diagram consists of:—

A. A Reiset absorption apparatus containing 100 c.c. of a 4 per cent. sodium hydrate solution for washing the air free from carbon dioxide.

B. A Jena flask, in which the soil to be treated is put; the flask is provided with a side tube.

C. A second Reiset apparatus containing 100 c.c. of a 4 per cent. sodium hydrate solution for absorbing the carbon dioxide set free in B.

D. A condenser for cooling the air passing into C to prevent the lubricant of the inlet tap being melted.

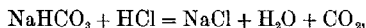
Procedure:—A weighed quantity of soil is put into the flask B and shaken up with 75 c.c. of carbon dioxide free water (any weight of soil

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may be used up to 50 grams, containing not more than 0.5 gram of lime); the apparatus is now connected up as in the figure except that the end Y of the rubber tube is connected directly with the pump, and a stream of air is drawn through the apparatus, so that all the atmospheric carbon dioxide is swept out; the pump is stopped and the Reiset C introduced between Y and the pump, and the pump started again, so that a steady stream of air free from carbon dioxide is drawn through the apparatus. 20 c.c. of strong hydrochloric acid are now run into B by means of the dropping funnel, and the contents of B gradually brought to the boiling point; the boiling is continued for 20 minutes to ensure all the carbon dioxide being swept into the Reiset C.

The titration is carried out in the lower part of the Reiset apparatus, into which the contents of the absorbing tube are washed, phenol-phthalein is added and normal hydrochloric acid run in until the pink colour begins to fade, then decinormal hydrochloric is run in until the colour is completely discharged, the reading of the decinormal hydrochloric acid is now taken, methyl-orange is added, and the titration continued until the methyl-orange shows an acid reaction; a second reading of the hydrochloric acid is now taken.

The difference between the two readings gives the volume of decinormal hydrochloric acid required in the equation,



and hence we get the weight of calcium carbonate originally present in the soil.

The object of employing normal hydrochloric acid in the first part of the titration is to prevent unnecessary dilution, but the liquid must be kept in motion so that the acid is never in excess at any point with consequent evolution of CO_2 .

The presence of aluminium and iron has been shown to interfere with the sharpness of the second colour reaction, consequently the sodium hydrate employed must be prepared from metallic sodium.

In order to get an exact reading at the end of the second titration a standard solution of methyl-orange, contained in a vessel of the same shape and size, and having an arbitrary tint of acidity should be employed, with which to compare the tint.

These precautions are some of those suggested by Brown and Escombe.

A preliminary blank experiment must be carried out in order to correct for:—

- (i) The amount of carbon dioxide originally present in the 100 c.c. of sodium hydrate used in the Reiset.
- (ii) The CO_2 contained in the air in the Reiset apparatus C before the soda solution is run into it.
- (iii) Any CO_2 in solution in the 20 c.c. of acid employed for decomposing the lime.

The following table gives the results of a series of experiments carried out for the purpose of testing the accuracy of the method; weighed quantities of ground Iceland spar, or a known volume of a solution of sodium carbonate, were treated by the above method, and the weight of calcium carbonate or sodium carbonate calculated from the carbonic acid absorbed.

| No. of Experiment | Weight of CaCO_3 taken (grams) | Weight of CaCO_3 found (grams) |
|-------------------|---|---|
| 1 | 0.057 | 0.056 |
| 2 | 0.105 | 0.104 |
| 3 | 0.242 | 0.245 |
| 4 | 0.542 | 0.541 |
| 5 | 0.564 | 0.559 |
| 6 | 25 c.c. = 0.0250 Na_2CO_3 | 0.0248 Na_2CO_3 |

The absorption of carbon dioxide in the Reiset apparatus is very perfect; the rate at which air may be passed through and still be completely freed from carbon dioxide is only limited by the overflow of the sodium hydrate solution.

When a series of calcium carbonate estimations have to be made the method is reliable and quick; one determination lasting about 45 minutes; but when only isolated determinations have to be made, the method of Hall and Russell is more expeditious because of the time involved in the preparation of solutions and other preliminaries.

The above method was employed for the estimation of calcium carbonate in some soils taken from the Royal Agricultural Society's farm at Woburn; the following table shows the results obtained: the first column gives the name of the plot from which the soil was taken; the second gives the weight of soil employed; the third gives the volume of acid in duplicate experiments used in the titration; the fourth gives the volume of acid required in a blank experiment; the fifth gives the calculated percentages of calcium carbonate.

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It will be seen that the duplicates agree except in one instance (in the first depth of plot 3 of the Rotation field), in which one low figure was obtained.

Plot 2 A in the Stackyard field is the well-known 'acid' plot, which has been continuously manured with ammonium salts, the fresh soil of this plot gives an acid reaction with litmus.

The percentage of calcium carbonate found in the first depth of this soil (0.053) was lower than that found in the first depths of any of the other plots but yet seemed inconsistent with its acid reaction.

| Sample of soil | Weight of soil in grams | Vol. of $\frac{N}{10}$ HCl in c.c. | Vol. of $\frac{N}{10}$ HCl in Blank Expt. | % of CaCO_3 |
|----------------------------------|-------------------------|------------------------------------|---|----------------------|
| Stackyard 2A, 1st depth, 1903... | 50 | 11.5, 11.4 | 8.9 | 0.053 |
| " 2A, 2nd " 1903... | 50 | 11.1, 11.1 | 8.9 | 0.044 |
| " 3, 1st " 1903... | 50 | 12.5, 12.4 | 8.9 | 0.070 |
| " 3, 2nd " 1903... | 50 | 10.9, 11.1 | 8.9 | 0.042 |
| " 4, 1st " 1876... | 50 | 11.6, 11.5 | 8.9 | 0.087 |
| " 4, 2nd " 1876... | 50 | 10.9, 10.9 | 8.9 | 0.066 |
| Rotation 3, 1st " 1903... | 50 | 11.9 (11.3), 12.1 | 7.3 | 0.089 |
| " 3, 2nd " 1903... | 50 | 10.9, 10.9 | 7.3 | 0.071 |

It was thought that this might be due to carbon dioxide being occluded by the soil particles; in order to test this, 50 grams of soil were digested with hydrochloric acid, filtered, washed and then stirred up with some water saturated with carbon dioxide, and allowed to dry in the air at the ordinary temperature; the carbon dioxide was then estimated by the method, when it was found that no carbon dioxide had been occluded.

A further experiment was carried out to test this point: 50 grams of plot 2 A were placed in the flask of the apparatus with water only, no hydrochloric acid being added, the mixture was boiled, and any gas evolved passed through the Reiset tower; it was found that no carbon dioxide had been absorbed; hence we must conclude that the calcium carbonate is genuinely present, and its presence will explain the fact that when this soil is stirred up with water, and the mixture kept for some weeks, the acidity slowly disappears, owing to the interaction between the acid and the carbonate.

THE RECENT WORK OF THE AMERICAN SOIL BUREAU.

By EDWARD J. RUSSELL, D.Sc. (LOND.),
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SINCE its inception in 1894 the American Soil Bureau has investigated many important problems and obtained results which are now common knowledge in this country, but its earlier Bulletins are altogether eclipsed in interest and far-reaching significance by a series recently published. In presenting an account of these it will be most convenient to set out first the purely scientific part of the work, and then the practical applications. This is the logical order and also the order in which the results were actually obtained.

SOIL FERTILITY.

Jethro Tull in 1733 published some consistent speculations on fertility based on the assumption that earth is the proper food of plants. If the surface of the soil is increased, the "pasture of the plant," as he quaintly terms it, increases also, and a greater yield is obtained provided the moisture and temperature conditions are favourable. Dung and cultivation both increase the surface, the former by fermentation, the latter by actual attrition; both methods can be used, but cultivation is better and cheaper—a man's wages then being 1s. a day—and dung may even be dispensed with.

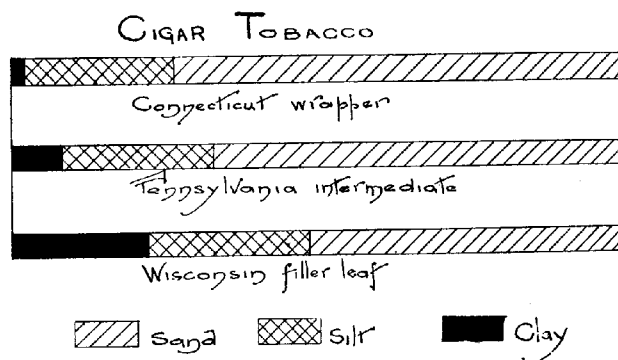
From the close of the 18th century the development of chemistry became extremely rapid and agriculture was soon brought within its sphere.

Many of the agricultural investigators were in the first instance chemists, and chemical conceptions of fertility naturally began to assume greater and greater predominance. These conceptions have been and still are extremely useful, but we recognise now that they are not complete.

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In America, on the other hand, soil fertility has been studied by physicists and physical chemists with the result that greater stress is laid on physical than on chemical properties, the latter in fact being almost disregarded.

The main ideas underlying much of the present work of the Bureau are foreshadowed in a bulletin published by Whitney in 1892¹, when he was Professor of Geology and Soil Physics at the Maryland Agricultural College, and Physicist at the Experiment Station. He examined a number of soils of known productiveness, and showed that in passing from type to type the agricultural properties are closely correlated with the texture of the soil as revealed by mechanical analysis. Physical characteristics, and especially texture, regulate the temperature, moisture content, and aëration, in short the "climate" of the soil, and their significance in determining the distribution and yield of crops must therefore be of the same order as climate in the ordinary sense of the word. They are the predominant factors in fertility.



This thesis was further developed in 1898². Typical tobacco soils from the various States were investigated, and a close connexion found between the quality of the crop and the texture of the soil. High quality ("wrapper") tobacco was produced on soil containing a large quantity of sand and a small proportion of clay, whilst low quality crops ("filler" tobacco) were associated with heavier soils, containing

¹ "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution," Whitney, Weather Bureau, *Bull.* No. 4, 1892.

² "Tobacco Soils of the United States," Whitney, Division of Soils, *Bull.* No. 11, 1898.

more clay and silt. These facts are well illustrated in the accompanying diagram, taken from Whitney's paper. By no scheme of manuring can the heavy soil be made to produce a wrapper tobacco, nor is it good economy to attempt to grow large crops of the filler type on soils naturally adapted to carry small crops of higher class tobaccos.

So successful was mechanical analysis in classifying these and other soils that it was adopted as the basis of the elaborate Soil Survey of the United States now in progress. An area of about 400 square miles is assigned to one or two experts and thoroughly covered by them; they then draw up reports which are issued, with an introduction by Professor Whitney, by the government. A pleasing feature about the reports is that each separate one is signed by the assistants actually in charge, instead of being anonymous publications or issued only in the name of the chief.

After stating the position and boundaries of the area under survey, a brief account of its history is given with special reference to agricultural development. A general statement about the climate follows, with statistics of mean monthly temperatures, rainfall, and dates of the latest spring and earliest autumn killing frosts. The geology of the district is next dealt with, and finally the separate types of soil are described in some detail. The type is considered as a whole, and particular care is taken to ascertain which crops are most successful. The central idea seems to be that to every type of soil in a given locality particular classes of crop are adapted, and it is no use, or at any rate it is not economical, to kick against the pricks and try to grow anything else. This does not mean that agriculture becomes stereotyped; fresh crops are continually being introduced by the Bureau of Plant Industry and the Soil Bureau proceeds to ascertain the soils to which they are best suited. For the purpose of the Survey it is considered sufficient to make full mechanical analyses, chemical analyses not as a rule being carried out.

In studying the methods and results of the Survey one has to bear in mind that it deals exclusively with types and not with variations within those types. However much we might like to know the chemical composition of the soil, we must certainly agree that the differences between the types are brought out more clearly and the types are more definitely described by a mechanical than by a chemical analysis; numerous instances of this could be quoted from English soils. In fact our whole conception of type usually rests on physical considerations.

Whitney and his co-workers, however, early realised that a mechanical

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analysis does not completely solve the problem. In some cases it broke down entirely, and classed as identical soils of widely different agricultural value; the Florida soils are of such interest in this connexion that they were dealt with separately¹. Some of these soils, the "pine lands," naturally produce good grass and pine and are excellent for market garden purposes. Their most remarkable feature is the evenness of their water content, about 4 % is present, and there is but little variation throughout the whole season. The "hammock soils," on the other hand, naturally produce oak, hickory, dog-wood, and other hard-wood trees and are suited for general agricultural purposes and "filler" tobacco. They contain about twice as much water as the pine soils, but the amount is not constant and fluctuates considerably. The Etonia scrub differs widely from both; it borders on the pine land, but the line of demarcation is very sharp. No grass is found, and only the most hardy desert plants grow, they form a dense growth about 5 ft. high, with thick leaves turned edgewise to the sun and in fact all the characteristics of desert vegetation. The few attempts to cultivate these soils have failed. No three soils could very well show greater vegetation differences, yet mechanical and chemical analysis represent them as identical.

| Kind of land | Organic matter | Gravel 2-1 mm. | Coarse sand 1-5 mm. | Medium sand .5-.25 mm. | Fine sand .25-.1 mm. | Very fine sand .1-.05 mm. | Silt .05-.01 mm. | Fine silt .01-.005 mm. | Clay |
|--------------------|----------------|-------------------|------------------------|---------------------------|-------------------------|------------------------------|---------------------|---------------------------|------|
| Etonia scrub | 1.24 | .23 | 3.34 | 27.43 | 58.60 | 7.60 | .55 | .20 | .87 |
| High pine land.... | 1.82 | 1.46 | 5.78 | 23.89 | 45.11 | 18.42 | .96 | .38 | 1.56 |
| Grey hammock... | 1.84 | .36 | 3.29 | 19.75 | 52.17 | 19.08 | .66 | .50 | 1.68 |

The subsoils show a similar identity.

Average amount of water present (April and May).

| | |
|----------------------|-------|
| Etonia scrub | 2.4 % |
| High pine land | 3.7 % |
| Hammock | 8.2 % |

There is no apparent reason why desert conditions should prevail on the scrub and not on the pine land, nor is it intelligible why the hammock should contain so much water.

¹ "Preliminary Report on the Soils of Florida," Whitney, Division of Soils, *Bull.* No. 13, 1898.

The soils are all poor, and the scrub is poorest of all, but the differences revealed in the table will scarcely account for the great differences in vegetation.

Whitney quotes other instances where present methods break down in the Catalogue of Soils¹, and in some of the later bulletins².

| | K ₂ O | CaO | MgO | P ₂ O ₅ | N |
|--|------------------|------|------|-------------------------------|------|
| Etonia scrub | ·003 | ·030 | ·013 | ·008 | ·028 |
| High pine land | ·007 | ·060 | ·020 | ·140 | ·028 |
| Grey hammock | ·009 | ·090 | ·036 | ·090 | ·042 |
| Average of American soils (Hilgard)... | ·216 | ·108 | ·225 | ·113 | |

One would hardly expect a mechanical analysis to give a complete account of a soil, however. The important factors are the temperature, moisture content, and aëration of the soil, and whilst these are mainly, they are by no means completely determined by the ultimate structure as revealed by mechanical analysis. Temporary artificial aggregates, behaving like natural ones, can be obtained by cultivation or manuring, yet no account of them is taken in mechanical analysis. Moreover the depth of the water-level and the nature of the intermediate strata are matters of the highest significance. The factors concerned interact in an unknown but complex way, and even if the separate effects were determined it would be a difficult problem to integrate them with certainty.

As a step in this direction, Whitney devised³ and Briggs developed⁴ an electrical method for finding the amount of water in the soil. The advantages of a method that allows determinations to be made *in situ* are obvious: not only can the records be made practically continuous, but after the apparatus is planted no further disturbance of the soil takes place. Carbon electrodes are buried in the soil, a rapidly alternating current is passed between them, and the resistance measured on a Wheatstone bridge. The electrical conductivity is stated to be nearly proportional to the square of the water content⁵; for more exact determinations the proper exponent can readily be ascertained.

¹ *Bull.* No. 16, 1899; see especially Lafayette, p. 115.

² See *Bull.* No. 22, p. 55.

³ Weather Bureau, *Bull.* No. 4, p. 83. See also Gardner, "Electrical Method of Moisture Determination in Soils," *Bull.* No. 12, Division of Soils, 1898.

⁴ Briggs, "Electrical Instruments for Determining the Moisture, Temperature, and soluble Salt Contents of Soils." *Bull.* No. 15, Division of Soils, 1899.

⁵ *Bull.* No. 12, p. 15.

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The theoretical basis of the method is not discussed in any of the bulletins I have seen, but it is somewhat as follows. The conductivity of a solution depends among other things on the number of ions present in a given volume, and this method assumes that

(1) for a given water content the number of ions in the soil solution is always the same,

(2) as the water increases, the ions increase, but in a much greater ratio, and as the water decreases the ions decrease and again to a much greater extent.

The method only holds so long as the soil contains somewhere about the optimum amount of water; it breaks down when there is an excess or great deficiency, but this of course does not prejudice its use. Keeping within these limits one can readily accept the second assumption and conceive a solution behaving in the manner indicated; it is nearly saturated with substances that readily dissociate on dilution, and the effect of adding a little water is to increase dissociation to a considerable extent and so increase the number of ions. On the other hand, when water is removed the ions unite again and the conductivity decreases. The difficulty is to accept the first, and to suppose that the concentration of the ions is constant for a given water content. If a soil contains 15 % of water one day in June and the same amount one day in September we have to assume that the concentration of the dissolved substances, or at any rate of the ions, is the same on both occasions, and that any changes which may have taken place, nitrification, removal of dissolved matter by plants, etc., are either so small as to be negligible or else counterbalance one another.

Strange as this doctrine is, it is nothing to what follows. In 1903, Whitney and Cameron published a remarkably curious paper on "The Chemistry of the Soil as related to Crop Production¹," wherein Chemistry, which had been relegated to the background in the previous work on Soil Types, is dismissed altogether. Amongst other novel propositions in this paper are:—

1. The solution constituting the soil moisture may be regarded as the culture solution of the plant and is normally sufficient for the plant's requirements.
2. This solution is of the same order of composition and concentration in all soils, such differences as exist cannot be correlated with differences in crop production.

¹ Bureau of Soils, *Bull.* No. 22. (In 1901 the Division of Soils was converted into the Bureau of Soils.)

3. The function of the soil is to hold up this solution and supply it to the plant.

4. A productive soil is one which supplies the solution in proper amount and must therefore possess certain physical properties, but its chemical composition is not of primary importance.

5. The function of fertilisers is not to supply plant food, but rather to modify the physical condition of the soil.

6. On the average farm the great controlling factor in the yield of crops is not the amount of plant food in the soil, but is a physical factor the exact nature of which is yet to be determined.

The first proposition is supported by some old experiments of Birner and Lucanus¹, who grew plants to maturity in well-water. In a later bulletin Whitney and Cameron² also grew plants in an aqueous soil extract.

The second proposition is liable to be misunderstood owing to an ambiguous statement referred to later on. The authors do not mean, I think, that the solutions are identical, but that they are of the same order of concentration. It was not found practicable to analyse the actual soil moisture in more than a few cases, owing to the extreme difficulty of separating it from the soil. Filtering methods caused changes in concentration, and the problem seemed insoluble till Briggs devised a very ingenious centrifugal apparatus by which much of the moisture is thrown off and can be collected. It was noticed that soils show great differences in the ease with which they part with their moisture even when the initial content is the same, and this important difference is being investigated, but in no case was the apparatus as efficient as a plant in removing the moisture. Analysis of the solution showed:—

| | Soil solution, parts per million | | | | Dry soil, parts per million | | | |
|----------------------------|----------------------------------|-----------------|-------|-------|-----------------------------|-----------------|------|------|
| | PO ₄ | NO ₃ | Ca | K | PO ₄ | NO ₃ | Ca | K |
| Sassafras loam, New Jersey | | | | | | | | |
| Wheat, good..... | 7.20 | 7.20 | 44.40 | 33.60 | 1.35 | 1.35 | 8.34 | 6.31 |
| " poor | 7.00 | .40 | 26.90 | 24.40 | 1.40 | .08 | 5.38 | 4.88 |
| Leonardtown loam, Maryland | | | | | | | | |
| Wheat, good..... | 6.30 | 1.44 | 16.20 | 21.60 | 1.38 | .32 | 3.56 | 4.75 |
| " " | 8.40 | 4.08 | 21.60 | 38.40 | 1.48 | .72 | 3.80 | 6.75 |
| " poor | 9.75 | 4.80 | 8.50 | 19.25 | 2.45 | 1.21 | 2.12 | 5.10 |

¹ *Landw. Versuchs. Stat.* 1866, vii. 128.

² Investigations in Soil Fertility, *Bull.* No. 23, 1904.

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The authors state that it is impossible to correlate these differences with the differences in crop production.

The method generally adopted was to vigorously stir 100 grms. of soil for three minutes with 500 c.c. of water, allow to stand for 20 minutes, decant and filter under pressure through a Chamberland-Pasteur filter¹. The first 150 c.c. are rejected owing to absorption by the filter, but equilibrium is then set up and the rest of the solution filters unchanged. The phosphoric acid, nitric acid, potassium, and calcium are determined by colour reactions, rapid methods being indispensable where several hundred samples have to be examined.

It is admitted that the solution thus obtained is not a very definite thing for it neither quite represents the soil moisture nor is it a saturated solution of the soil constituents. But the method is believed to give comparable results, and these are all that are wanted. The colour tests are said to be very reliable. Messrs Taylor and Mooney examined certain types of soil showing marked differences in productiveness, 147 soils were investigated and the results are set out in the paper. The mean results are given in parts per million of dry soil as:—

| | |
|--|-------|
| Phosphoric acid (PO ₄) ... | 7.64 |
| Nitric acid (NO ₃) | 5.47 |
| Calcium (Ca) | 11.67 |
| Potassium (K) | 22.74 |

Whitney and Cameron add, "While these figures will undoubtedly vary somewhat as a result of wider investigations, it is believed that they represent closely the average figures for the great majority of cultivable soils as regards these several constituents, which the procedure used in this investigation will show." This ambiguous sentence might seem to imply that the solutions are fundamentally identical, but the figures will not bear this interpretation. I take it the authors mean that these figures indicate the *order* of concentration, not the *actual* concentration. The highest and lowest values are:—

| | Highest | Lowest |
|--------------------|---------|--------|
| Phosphoric acid... | 40.60 | .59 |
| Nitric acid | 62.00 | Trace |
| Calcium | 102.85 | Trace |
| Potassium | 62.20 | 4.93 |

¹ Briggs, "Filtration of Suspended Clay from Soil Solutions," *Bull.* No. 19, 1902.

If we group the figures to show their distribution we find in the case of phosphoric acid the number of instances where there are

| | | | |
|---|-------|----|---------|
| Less than 5 parts per million of dry soil | = 120 | or | 27.97 % |
| 5 to 10 " " " | = 193 | " | 44.99 " |
| 10 " 20 " " " | = 105 | " | 24.47 " |
| 20 " 30 " " " | = 8 | " | 1.86 " |
| 30 " 40 " " " | = 3 | " | .70 " |
| | 429 | | 99.99 % |

A similar distribution can be worked out for the other constituents.

Abundant proof is given that the differences in the chemical composition of the solutions are in no way related to the productiveness of the soils; to take two instances out of many:—

| | PO ₄ | NO ₃ | Ca | K |
|---|-----------------|-----------------|-------|-------|
| Cecil clay, 25 to 30 bushels of wheat | 11.04 | 2.87 | 22.25 | 44.16 |
| " 2 to 3 " " " | 12.83 | Trace | 22.49 | 35.71 |
| Cecil sandy loam, 15 to 20 bushels of wheat | — | .92 | 20.69 | 32.37 |
| " " 2 " " | — | .66 | 19.58 | 34.13 |

or if instead of taking individual examples we take the mean of a number:—

| | PO ₄ | NO ₃ | Ca | K |
|--|-----------------|-----------------|-------|-------|
| Sassafras loam, 6 good wheat soils ... | 8.36 | 5.46 | 12.35 | 21.46 |
| " " 6 poor " " ... | 5.60 | 8.97 | 24.86 | 21.05 |

Whitney and Cameron then proceed to consider the functions of fertilisers. They argue that fertilisers may temporarily, but cannot permanently, increase the amount of dissolved matter in the soil moisture. This latter being a saturated solution of all the substances occurring in the soil it follows from Nernst's well-known law that addition of the ions of potassium would simply throw some potassium out of solution by causing recombination of dissociated or hydrolysed solutes. The temporary increase is shown in the following case:—

| | PO ₄ | NO ₃ | Ca | K |
|---|-----------------|-----------------|------|-------|
| Tobacco field, Windsor sand, Unmanured strip | 3.85 | 4.90 | 8.63 | 20.90 |
| " " 400 lbs. of 'bone and potash' | 6.60 | 7.70 | 9.90 | 25.74 |
| Gain, parts per million of dry soil | 2.75 | | | 4.84 |

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The samples are taken to a depth of 12"; and we might estimate the gain at about 10 lbs. of phosphoric acid (P_2O_5) and 18 lbs. of potash (K_2O). Unfortunately we are told nothing about the "bone and potash," but it is obvious that a good part of the added fertiliser is in the soil moisture. It is stated to have been "amply demonstrated" that these increases "disappear with surprising rapidity," but the proofs are not set forth. This is very unfortunate, because the point is an important one.

They find other reasons in support of their contention that fertilisers do not supply plant food. The effect of fertilisers is not cumulative; at Rothamsted, for instance, annual additions of manure far in excess of actual plant requirements only maintain a high crop and do not indefinitely increase it. Nor are fertilisers always consistent in their action. Instances are quoted where on the same soil phosphates give a considerable increase in crop some years but none at all in others, they even sometimes decrease the crop.

Again, the great differences in yield in passing from one type of soil to another, or even in some instances on the same type, cannot be altered by manuring. The Cecil clay in North Carolina yields 8 bushels of wheat, and the same soil in Maryland yields 25 to 30 bushels; by no scheme of manuring can the 8 bushels be much increased. By efficient cultivation, however, some North Carolina soils will give 25 bushels, but here the physical condition of the soil is altered. We are, in fact, back to Jethro Tull's position, that the farmer's business is to cultivate and not manure. Professor Whitney informs me that he is now taking up the question of soil management.

These are Whitney and Cameron's arguments, as far as I understand them. Two or three matters may be discussed.

The idea of regarding soil moisture as a culture solution is a very interesting one and is capable of considerable development. Pfeffer¹ is quoted to show that there is no evidence for the old theory that cultivated plants excrete acids (except carbonic acid) from their roots to dissolve mineral matter; and in fact the assumption is both cumbersome and unnecessary, all the phenomena being explained more easily without it. If the solution can be renewed in the soil quickly enough, it obviously suffices for plant growth. Renewal, then, becomes an important factor, it is partly brought about by the molar stream caused by transpiration, partly by the molar stream produced by

¹ *Physiology of Plants*, Eng. ed. Vol. 1. p. 171, 1900.

capillary movement, and partly by the diffusion stream of salts towards the roots depending on the osmotic pressure gradient between the layers in contact with the roots and those further off. Assuming Briggs' figures to be correct it is evident that the quantities of potassium, calcium, and phosphoric acid delivered to the roots in the transpiration stream, would, even if completely taken up, only be a small proportion of what the plant actually absorbs; moreover, the mineral matter is mostly absorbed in the early stages of the plant's life and transpiration is most rapid when the leaf surface is most fully developed. The tendency of surface cultivation, by checking evaporation, would seem to be to decrease the amount of capillary movement. If the above reasoning is sound the main source of mineral matter must be looked for in the diffusion stream.

It is not at once obvious that this can be of great moment. The Rothamsted grass plots have been annually dressed for 50 years with large quantities of soluble substances and their herbage altered in consequence, but the effect stops at the edge of the plot and there is a sharp change in passing from one to another. Vertical movements, due to molar currents, can be traced, but lateral movement produced by diffusion through appreciable distances seems almost non-existent even after 50 years. On the other hand it is highly probable that diffusion goes on fairly rapidly through the molecular distances of capillary films provided the gradient is sharp enough, and this can be secured by having a reserve of readily soluble matter in the soil particles. The substance may be either dissolved, or temporarily "forced back" out of solution, the point is that it can readily redissolve as soon as the partial pressure of the particular ions decreases, and it is there whenever it is wanted.

Whitney and Cameron appear to overlook this entirely, but I think it would be agreed that soil solutions must be regarded dynamically, and not statically. The equilibrium ultimately attained is of minor importance compared with the ease with which equilibrium can be reestablished after a slight disturbance. The plant only has a relatively short space of time to take up the greater portion of its mineral matter, and even then there are checks and delays; unless the amount removed from the moisture near the roots can be rapidly replaced so that every favourable opportunity for growth may be seized we cannot expect the plant to do well. It is of purely academic interest to know that if there were time enough the soil would furnish sufficient nourishment.

The authors assume—and the assumption is a necessary part of their argument—that plant growth is independent of the concentration of the culture solutions. In a later bulletin they show that this is true of transpiration and argue that it must therefore be true for growth. We doubt, however, whether a plant physiologist would agree to this. There may be a certain parallelism between the effect of varying conditions on transpiration and on assimilation, but there are also sharp differences, and it is not safe to take one as a measure of the other. The two phenomena are not causally connected, and on a point of vital importance like this we should have preferred direct and unexceptionable proof. There is no necessary connexion even between transpiration and absorption of mineral matter. The indirect evidence adduced in the present bulletin seems to me to go quite against their case. "In water culture experiments the proportion of solid matters is usually maintained at between 0.5 and 2 parts in a thousand of water (i.e. 500 to 2000 parts per million), and no observations have indicated any material difference in the yield within these limits, although above *or below* these concentrations crops may suffer." (The italics are mine.) It seems to me that the crux of the question lies in the words "*or below*," for the solutions Briggs obtained from soils contained much less than 0.5 parts of dissolved matter per thousand.

The effect of varying amounts of carbon dioxide, heat, and illumination on assimilation has recently been carefully examined, and in all cases a small increase in any of these quantities causes increased assimilation up to a certain point, when these small increases have little or no effect, finally further increases are detrimental to assimilation. The effect of dissolved mineral matter has perhaps not been so carefully investigated, but the presumption is that it would behave in the same way, at any rate we should want very cogent proofs to convince us that it did not. Practical experience is that successive additions of mixed soluble salts of nitrogen, potassium, and phosphoric acid at first increase the crop, then the return diminishes, finally excessive amounts are injurious.

Whitney and Cameron do not deny that fertilisers increase the crop. They argue from Nernst's law that the addition of a potassium salt cannot permanently increase the concentration of potassium ions in the soil moisture, but they are surely wrong here. If there were 100 potassium ions in a given volume of a saturated solution to begin with and 100 more were added, it follows from Nernst's law that there may be precipitation and less than 200 will then be left in solution,

perhaps about 170, but not as few as 100. One of the leading American chemists, Noyes, has made a quantitative examination of the law and his results are very interesting in this connexion.

What is the function of a fertiliser? Whitney and Cameron say they do not know. Having dismissed, on altogether inadequate grounds as we think, its function as plant food, various other possibilities are suggested, but decision is reserved till further work has been done.

The bulletin is somewhat difficult reading, because it is at times hard to reconcile statements occurring on different pages, and a number of debateable side issues are introduced. But if we strip off the parts which appear to be inconsistent or non-essential we arrive at the following main idea:—

Of the various factors influencing the yield of crops, the addition of mineral substances for plant food is only of minor importance.

Our English idea is:—

Other factors remaining constant, addition of mineral substances for plant food will increase the yield of crops.

These views are not incompatible with one another; we do not, unfortunately, make any experiments on cultivation or soil management, but we know it is extremely important, as are also the other factors, season, type of soil, etc.

In their latest bulletin¹ Whitney and Cameron aim at tracing the unknown physical factor which, in their opinion, controls the yield on an ordinary farm, but without success. Neither the movement of water in the soil, nor the rate of evaporation, nor the amount of water a soil will give up to seeds showed any connexion with fertility in the cases examined.

They begin, too, to study variations within the type. Instances of this are familiar enough to us in England: cases occasionally arise, in fact, where soils of the same formation with approximately the same chemical composition and physical structure show considerable differences in crop production. Whitney and Cameron selected two Cecil clays of very different productiveness but of identical chemical and physical constitution, they prepared aqueous extracts and used these as culture solutions for wheat seedlings. The extracts contained in parts per million:—

¹ "Investigations in Soil Fertility," Whitney and Cameron, *Bull.* No. 23, 1904.

| | NO ₃ | PO ₄ | K | Ca |
|---------------|-----------------|-----------------|-----|-----|
| Good soil ... | 3.2 | 1.6 | 3.6 | 3.2 |
| Poor soil ... | 3.5 | 1.6 | 2.0 | 2.8 |

and they were both neutral. Yet in spite of their identity as shown by analysis they gave very different results. The seedlings in the "good soil" extract had decidedly larger and healthier roots and a somewhat better development of leaves. More rigorous transpiration had taken place, 16 plants had in 30 days transpired 277.1 grams of water from the good soil extract and 171.7 from the poor soil. They then transferred the plants from the good to the poor extract and transpiration and growth were at once checked. On the other hand the plants moved from the poor to the good extract showed distinct improvement.

Similar results were obtained with a good and a bad Leonardtown loam; a photograph of the plants, taken from this bulletin, is reproduced here by kind permission of Professor Whitney.

Whilst, then, the differences observed in soils in passing from type to type can often be correlated with the physical structure the variations within the type cannot, for they extend also to the soil extracts. Further investigation of this question will constitute a very pretty chemical problem.

WORK ON SOIL PHYSICS.

Although not properly coming within the scope of this review, it is impossible to pass over the work of Briggs, King, and others, owing to its intimate connexion with soil fertility.

The method of mechanical analysis adopted is described in Bulletin 24 (1904)¹. In principle it is the sedimentation method of Osborne and Knop, but the process is hastened by centrifugal action. Instead of adopting Schloesing's modification as we do, and breaking up the soil aggregates by a preliminary treatment with acid, they shake the soil in a motor-driven shaker with water containing a little ammonia. This treatment is considered sufficient to reduce the soil to its ultimate

¹ "The Centrifugal Method of Mechanical Soil Analysis," by L. J. Briggs, F. O. Martin, and J. R. Pearce.

particles. The difficulty with mechanical analysis is of course to represent the results in some simple way so as to facilitate comparison between one set of figures and another; a method is promised for a future bulletin.

The connexion between mechanical composition and physical properties is being carefully examined. Briggs¹ in 1897 applied certain dynamical principles to the movements of water in soil and found that they were related to, and could in a general way be deduced from, the structure of the soil as determined by mechanical analysis. But this is not quite true of the movements of dissolved salts; to some extent they follow the movements of the soil water, but not altogether. Thus King, in some papers published last year, found that there is a tendency for the ions Ca , NO_3 , Cl , SO_4 to work upwards and accumulate in the surface soil, K ions show this to a much less extent, and the ions HCO_3 , SiO_3 , and PO_4 scarcely show it at all.

The problem is of obvious importance in its relation to soil management.

A very important subject is seriously attacked for the first time in Bulletin No. 25². Buckingham investigates from a mathematical standpoint the effect of a difference of pressure on the rate at which air penetrates by transpiration into the soil, and then proceeds to actual measurements of the rates of diffusion and transpiration. The results show when the soil is still and the air has no lateral motion (like the movement of wind), *i.e.* when the driving force is simply a change in barometric pressure, the effects of transpiration are small compared with those produced by diffusion. The rate of diffusion was empirically found to be proportional to the square of the pore space³ (*i.e.* the space not filled by soil or water) and is to a great extent independent of the texture of the soil.

ALKALI SOILS.

No notice of American work would be complete without a reference to this great question, which turns up also in some of our Colonies and dependencies. The general features of the problem are well known. Owing to the slight rainfall, the soluble matters always being formed

¹ "The Mechanics of Soil Moisture," by L. J. Briggs, *Bull.* No. 10.

² "Contributions to our knowledge of the Aëration of Soils," E. Buckingham, 1904.

³ Buckingham calls it the "porosity," but it is a pity to use an abstract noun for a concrete quantity with which the useful expression "pore space" has for some time been associated.

in the soil are not washed away but remain; if much evaporation takes place the soil moisture in the surface layers becomes so concentrated that growth is impossible, and the land first of all runs to weeds and finally becomes a desert. There are two special cases, the salts may be harmless in themselves but injurious because of their excess, or the salts may be actually poisonous. In the first case the salts are usually sodium and magnesium chlorides and sulphates, and are generally spoken of as white alkali, of which plants can tolerate about 15,000 lbs. per acre in the first foot, corresponding to about 45 % of the air-dried soil.

In the second case the dangerous salt is sodium carbonate; it decomposes the plant roots and other organic matter that may be present, forming black products, hence its name black alkali. Only small quantities are tolerated by plants. Hilgard showed that addition of sufficient calcium sulphate converted the sodium carbonate into sodium sulphate. The subsequent treatment then becomes the same as for the first case. Addition of calcium salts has the further effect of enabling the plant to tolerate more dissolved matter.

Two methods of attack have been developed. One is to investigate the way in which the salts are formed and to map out their movements in the soil. Means can then be devised, now that the laws of soil physics are fairly well known, to regulate these movements and keep the salts below the root range of the plant. The ordinary crops of the district can then be grown.

The second method is to frankly accept the situation and seek plants like the Australian salt bush, which will tolerate large quantities of mineral matter. This is only a *dernier ressort*, adopted when there is no prospect of the former succeeding.

The origin of the soluble substances in any particular case is ascertained by studying the geology of the district. The interaction of the soluble substances is, however, somewhat remarkable, and one phase of the question is discussed in Bulletins Nos. 17 and 18¹. Setting out from Nernst's law it is shown that the solubility of a salt must increase when another salt containing no common ion is added, but decreases when the added salt contains a common ion. Thus addition of sodium chloride or magnesium chloride increases the solubility of calcium

¹ "Soil Solutions, their nature and functions and the classification of Alkali Lands," by F. K. Cameron, *Bull.* No. 17, 1901.

"Solution Studies of Salts occurring in Alkali Soils," by Cameron, Briggs, and Seidell, *Bull.* No. 18, 1901.

sulphate, whilst addition of calcium chloride decreases it, the ion calcium being common to both. The solubility in presence of sodium chloride at 23° is given in the following table:—

| Grams of NaCl per litre added | Grams of CaSO ₄ dissolved per litre |
|----------------------------------|---|
| 0.0 | 2.05 |
| 4.95 | 3.02 |
| 30.19 | 4.37 |
| 129.5 | 7.50 |

But when calcium chloride is present:—

| Grams of CaCl ₂ per litre added | Grams of CaSO ₄ dissolved per litre |
|---|---|
| 0.0 | 2.056 |
| 7.489 | 1.241 |
| 32.045 | 1.080 |
| 280.803 | .203 |
| 367.850 | .032 |

It follows that if a saturated solution of calcium sulphate is moving through the soil and comes in contact with a solution of calcium chloride, precipitation will occur and a bed of gypsum result, on the other hand if a solution of sodium chloride percolates through a soil containing gypsum it will take up far more of this than pure rain-water would do. As the rainfall in the alkali districts is only small and not regularly distributed—weeks may elapse without rain—irrigation is largely adopted. The water, being drawn from rivers, is never pure, and the interest of the foregoing investigation lies in the fact that it enables one to predict the effect of the water proposed for use on the soluble substances in the soil, effects which would otherwise be quite unexpected and might even be disastrous.

The determination of the soluble salts in the soil is rapidly made by the electrical method of Bulletins 8 and 15¹. As the amount of soluble salt increases the conductivity also increases, and not only can comparative results be obtained, but, when the nature of the dissolved

¹ "An Electrical Method of determining the soluble Salt Content of Soils," Whitney and Means, *Bull.* No. 8, 1897; "Electrical Instruments for determining the moisture, temperature, and soluble Salt Content of Soils," Briggs, *Bull.* No. 15, 1899.

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matter has been ascertained, its absolute amount can be measured more accurately than by extraction with water.

A good idea of the method of surveying an alkali district may be obtained by reading Bulletin 14¹. The town of Billings, Montana, lies in a fertile valley originally showing no signs of "alkali." As, however, the annual rainfall is only about 13 inches it was necessary to irrigate, and then trouble from alkali set in. The district was thoroughly explored by T. H. Means, maps were drawn up showing the salt content of the soil, and the cause of the trouble discovered, all in about six weeks. It appeared that excessive amounts of irrigation water had been used, and that owing to the absence of underdrainage it could not get away, but had seeped through the land, dissolving the soluble sodium and calcium salts present and causing them to accumulate in the surface soil, where the solution became more concentrated by evaporation. The trouble was very pronounced in fields at a lower level. When the cause of the mischief had been located it was easy to suggest remedies. The farmers were instructed to use less water, to cultivate thoroughly so as to reduce evaporation, and to improve the drainage.

In other cases surface flooding and drainage have given remarkable results².

Alkali lands represent the upper limit of soluble matter in the soil possible for plant growth. This aspect of the question has been discussed jointly by a chemist and a plant physiologist in an excellent report issued by the Department of Agriculture³.

PRACTICAL APPLICATIONS.

The first impression of the practical man on reading these bulletins would be that they were too scientific and too little *ad hoc* to be of any possible utility, but that view is not held in America. Two special applications of the work of the Soil Bureau may be mentioned.

Observing that certain Connecticut soils had the same mechanical analysis as the high class tobacco soils of Sumatra, Whitney tried replacing the old Connecticut varieties by the more valuable Sumatra

¹ "The Alkali Soils of the Yellowstone Valley," Whitney and Means, *Bull.* No. 14, 1898.

² *Report of the Secretary of Agriculture for 1904*, p. 70.

³ "Some Mutual Relations between Alkali Soils and Vegetation," Kearney and Cameron, *Report*, No. 71, 1902.

tobaccos¹. To ensure favourable climatic conditions the whole field had to be covered with cheese cloth. Whitney introduces a delightfully human touch when he says, "there was a good deal of adverse criticism in the valley of the idea of attempting to change the character of the leaf, as the Connecticut Havanna seed had been grown there for upwards of 100 years." But the success of the experiment appealed to the practical man, and in spite of the great initial expense the cultivation of the new variety is being taken up.

Other instances could be quoted where important practical results have followed from the Survey. Yet the cost of this is little more than a farthing an acre.

Probably no country has ever had to deal with a more serious agricultural question than alkali land, compared with which the problem of our own derelict lands is insignificant. The scientific aspects of the matter are being carefully attacked, and already sufficient is known to enable the Bureau to suggest methods of reclamation. The Secretary reports that much of the land is now so far improved that shallow rooting crops can grow and in some cases even the deep rooting lucerne—one of the American farmers' staple crops—flourishes. In one of the districts mentioned the land is said to have risen from a purely nominal value to \$250 or \$300 per acre, the total cost of reclamation being but a small fraction of this.

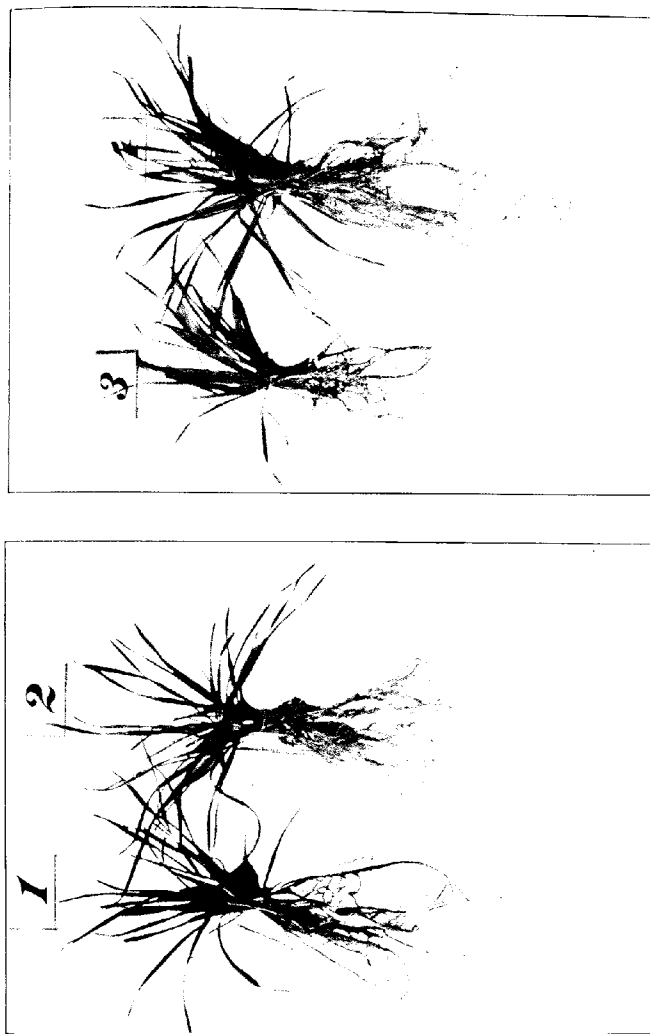
The United States Department of Agriculture furnishes us with a striking example of what can be done by a central staff whose sole business is to attack general questions, discover the underlying principles, and furnish the local colleges and experiment stations with methods of investigation, leaving to them the application to their particular conditions. No one will suppose that general scientific principles can be satisfactorily investigated at a college or station with multifarious activities and important local duties, and yet it is being recognised that these general scientific principles are of vital importance in agriculture. At any rate the Americans see this clearly enough, and the Report of the Secretary of Agriculture for 1904 is most convincing reading. A more optimistic report can scarcely be imagined; 1903 had been considered the most prosperous year on record for the farmer, but it was eclipsed by 1904. During the last five years the value of farm products has increased 42%, and the total value works out to nearly five thousand million dollars. The

¹ "Growing Sumatra Tobacco under shade in the Connecticut Valley," Whitney, *Bull.* No. 20, 1902.

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Secretary measures this "unthinkable aggregate" by some comparisons, given with a profuseness and an exuberant enthusiasm engendered by years of increasing prosperity. Land has risen in value, the number of depositors and the amounts deposited in the banks of the Agricultural States have doubled or trebled during the last few years, and in other ways the increased well-being of the farmer is showing itself. This result is all the more striking when one remembers that on the whole the period has been one of some commercial depression.

In concluding this review I wish to thank Professor Whitney, Chief of the American Soil Bureau, who has kindly furnished me with a number of typical bulletins, and has given me other help.



Development of wheat seedlings in aqueous extract of soil :

1. From poor Cecil clay.
2. From good Cecil clay.
3. From poor Leonardtown loam.
4. From good Leonardtown loam.

A CONTRIBUTION TO THE STUDY OF FACTORS AFFECTING THE QUALITY AND COMPOSITION OF POTATOES.

By S. F. ASHBY, B.Sc.,

Carnegie Research Scholar, Rothamsted Experiment Station.

THE work was undertaken with the hope of establishing some connexion between the characters of soils as shown by chemical and mechanical analyses, and the quality and composition of the potatoes grown on them. As regards quality, most attention has been given to the occurrence of 'blackening' after cooking, especially after a second warming up, and an attempt has been made to get at the cause of this phenomenon. This defect has been often complained of by potato growers and dealers, and seriously affects the price of samples marketed for consumption in towns where the largest buyers are hotels and restaurants which demand a potato capable of keeping its colour after a second steaming. 'Blackening' is often associated with sandy soils heavily manured with farmyard dung or town manure, and it has been observed in tubers grown with spring dressings of kainite; concordant opinions, however, are not to be had from practical men, and in fact the defect may arise on the most widely different types of soil. In order to exclude disturbances due to variety, 'Up to Date,' as one of the most widely grown sorts, has alone been investigated.

SOILS AND POTATO SAMPLES OF THE SEASON 1903.

During the summer of 1903 samples were taken of soil and subsoil from two soils in the neighbourhood of Dunbar, one, at North Belton, from a field which produces potatoes showing a tendency to blacken, and the other at Thornton Loch, from land that can be depended on for a good quality crop. Soil and subsoil were each sampled to a depth of 9 inches. In the autumn samples of potatoes from these soils were kindly forwarded by Mr J. D. Bowe, Dunbar, by whom the soils in

question had been pointed out. Both soils are of 'drift' origin but preserve the character of the underlying Old Red Sandstone rock.

During the autumn a visit was made to Boston, Lincs., and samples of soil and subsoil were taken from two fields on the farms of Mr J. H. Dennis, to whom I am indebted for help and information. Samples of potatoes just raised from these soils were also secured. The soil designated 'warp A' had only recently been reclaimed, and was carrying its first crop of potatoes. It is separated from the sea by a marsh several miles wide. The 'warp B' soil lies two miles further inland and has been under cultivation for a much longer time. Both soils are of natural formation, and have not been produced by artificially regulated deposit like those of the Humber district. Oats preceded the potato crop on both soils, and the latter received a dressing of about 12 tons of farmyard manure, and an artificial mixture containing 5—6 p.c. ammonia, 20—25 p.c. phosphates, and 5—6 p.c. potash at the rate of 6 cwt. to the acre. Two samples of potatoes were obtained from 'warp A' field, one from a portion where the growth had been normal, and the other from a part where the haulm had died off prematurely owing to disease.

A sample of potatoes was obtained from the Royal Agricultural Society's experimental farm at Woburn, grown on soil of which a mechanical analysis had been made at the Rothamsted Laboratory.

COOKING TEST.

The potatoes peeled and unpeeled were steamed under atmospheric pressure for one hour, allowed to get quite cold and again steamed for half-an-hour, and after cooling broken into halves either across or lengthwise. Some were cooked by boiling in water, and after cooling were given a steaming for half-an-hour. The results are arranged in the order of quality.

1. Thornton Loch. Good colour. No 'blackening' at heel end.
2. Woburn. " Slight " " "
3. Warp B. Stronger. Darkening at heel end.
4. North Belton. Blackened at heel end.
5. Warp A (mature) } Very white and waxy and much
6. " A (immature) } blackened in cortex and at heel end.

In no case was the 'blackening' very marked, and with the exception of the samples from 'warp A' was confined to the heel third of the tuber, being most evident near the scar marking the place of attach-

ment to the rhizome. In the case of the 'warp A' samples the blue-black discolouration extended up the cortex towards the seed end. The appearance was least marked in the potatoes which were boiled, and those cooked in the skins were always more 'blackened' than the peeled tubers with similar treatment.

MECHANICAL ANALYSES OF SOILS.

The method employed was that described by Hall¹, and the calcium carbonate determinations were made with the apparatus devised by Hall and Russell². The results are set out in Table I, the stones and calcium carbonate being calculated on the air-dry material.

It is evident that all the soils fall within the categories of 'sand' and 'sandy loam' in virtue of the high proportion of grit and sand particles, and the low amounts of 'Klay.' The Thornton Loch soil and subsoil show a very even distribution of all grades, the fractions ensuring porosity being well balanced by an adequate supply of the finer particles which give retentiveness.

The North Belton soil, on the other hand, is rather short of the finest fractions. The 'warp A' soil shows a very unusual composition with its very high percentage of 'sand,' absence of grit and stones, and extremely low amounts of fine silt and 'Klay.' The 'warp B' soil is better balanced with a higher 'Klay' content, but is also lacking in 'grit' and stones to counteract a tendency to 'run' and set. The best potatoes (see 'cooking test') are from the light soils with the most 'Klay,' Thornton Loch with its model composition standing first, and the bad cookers from the soils deficient in the finest particles.

CHEMICAL ANALYSES OF SOILS.

These are given in Table II. The citric acid soluble potash and phosphoric acid were determined by Dyer's method³. 'Soluble humus' was determined in 5 grams of soil rubbed up with dilute acid and allowed to stand 1 hour, thrown on a large Buchner filter, washed free from acid and treated with ammonia, using the filter pump (1 part strong ammonia and 1 part water) till the filtrate came away colourless. The dark liquid was evaporated and dried at 100° C. and weighed, and after ignition again weighed, the difference being set down as 'soluble humus.'

¹ A. D. Hall, *The Soil*, 1901, p. 48. *Trans. Chem. Soc.*, 1904, Vol. LXXXV. p. 950.

² *Trans. Chem. Soc.*, Vol. LXXXI. p. 81, 1902.

³ B. Dyer, *Journ. Chem. Soc.*, 1894, Vol. LXV. p. 115.

TABLE I. Mechanical analyses of soils.

| | Stackyard Field, Woburn | | North Belton, Dunbar | | Thornton Loch, Dunbar | | 'Warp A,' Boston | | 'Warp B,' Boston | |
|---|-------------------------|---------|----------------------|------------|-----------------------|---------|------------------|---------|------------------|------------|
| | Soil | Subsoil | Soil | Subsoil | Soil | Subsoil | Soil | Subsoil | Soil | Subsoil |
| Stones, over 3 mm. (determined on entire sample) | 0.00 | 0.00 | 11.37 | 12.66 | 9.65 | 5.41 | 0.11 | 0.00 | 0.00 | 0.00 |
| Moisture dissolved by acid | 1.83 | 2.25 | 4.30 | 3.27 | 3.14 | 3.00 | 4.40 | 5.56 | 3.23 | 3.52 |
| Loss on ignition | 3.84 | 2.70 | 6.92 | 5.70 | 6.16 | 4.78 | 6.95 | 6.16 | 6.35 | 5.35 |
| Calcium carbonate | — | — | 0.15 | under 0.10 | 0.31 | 0.19 | 0.90 | 0.78 | under 0.10 | under 0.10 |
| Fine gravel, 8-1 mm. | 1.01 | 1.02 | 8.00 | 1.14 | 0.99 | 0.88 | 0.23 | 0.00 | 0.00 | 0.00 |
| Grit, 1-2 mm. | 49.91 | 50.12 | 33.80 | 36.79 | 23.66 | 21.70 | 65.72 | 66.13 | 53.36 | 53.04 |
| 1st sediment, 2-0.4 | 16.11 | 15.85 | 28.00 | 26.07 | 38.18 | 35.60 | 8.75 | 9.89 | 12.32 | 11.00 |
| 2nd " 0.4-0.1 | 11.05 | 12.32 | 5.55 | 5.44 | 5.86 | 7.08 | 8.40 | 5.85 | 7.89 | 7.83 |
| 3rd " 0.1-0.04 | 3.50 | 3.89 | 8.40 | 4.58 | 5.86 | 7.08 | 1.91 | 3.57 | 2.43 | 2.70 |
| 4th " 0.04-0.02 | 2.06 | 2.05 | 2.40 | 3.84 | 9.48 | 14.82 | 2.64 | 3.70 | 14.66 | 16.58 |
| 5th " 0.02 and less | 9.68 | 8.56 | 6.56 | 9.52 | 100.22 | 100.17 | 100.14 | 99.98 | 100.57 | 100.12 |
| Total (excluding stones and calcium carbonate) | 98.99 | 98.97 | 98.93 | 99.35 | 100.22 | 100.17 | 100.14 | 99.98 | 100.57 | 100.12 |

TABLE II. Chemical analyses of soils.

| | North Belton, Dunbar | | Thornton Loch, Dunbar | | 'Warp A,' Boston | | 'Warp B,' Boston | |
|---|----------------------|-----------|-----------------------|---------|------------------|---------|------------------|-----------|
| | Soil | Subsoil | Soil | Subsoil | Soil | Subsoil | Soil | Subsoil |
| Water..... | 1.72 | 2.23 | 1.08 | 2.06 | 1.85 | 1.72 | 2.08 | 2.23 |
| Loss on ignition | 6.92 | 5.70 | 6.16 | 4.78 | 6.95 | 6.16 | 6.35 | 5.35 |
| Nitrogen..... | .171 | .139 | .162 | .087 | .223 | .116 | .184 | .134 |
| Potash, K ₂ O..... | .286 | .320 | .460 | .527 | .532 | .494 | .629 | .645 |
| Citric sol. K ₂ O..... | .01 | .01 | .023 | .02 | .04 | .03 | .017 | .01 |
| Phosphoric Acid, P ₂ O ₅ | .16 | .129 | .120 | .042 | .125 | .103 | .189 | .186 |
| Citric sol. P ₂ O ₅ | .094 | .094 | .022 | .024 | .024 | .024 | .084 | .084 |
| Calcium carbonate, CaCO ₃ | .150 | under .10 | .314 | .187 | .302 | .3780 | .08 | under .10 |
| Lime, CaO..... | .771 | .771 | .70 | .70 | 1.175 | 2.50 | .02 | .02 |
| Magnesia, MgO..... | .66 | .63 | .50 | .50 | .310 | .310 | .310 | .310 |
| Ferric oxide, Fe ₂ O ₃ | 4.74 | 4.18 | .15 | .14 | .10 | .10 | .14 | .15 |
| Manganese oxide, Mn ₂ O ₃ | .21 | .13 | .15 | .14 | .10 | .10 | .14 | .15 |
| Insoluble residue | 84.35 | 84.22 | 85.18 | 85.16 | 85.11 | 82.88 | 83.91 | 83.00 |
| Residue after treatment | .49 | .70 | .15 | .52 | .48 | .19 | .80 | .58 |

All the soils show high nitrogen figures, and so also do the warp subsoils. The total potash is correlated with the amount of 'Klay,' and is very low in the North Belton soil. The 'citric acid soluble' potash is very low in North Belton and 'warp B' soils, and is probably below the limit of safety for a crop like potatoes. Phosphoric acid is lacking in none of the soils, and the citric acid figures indicate high availability throughout. Calcium carbonate is very deficient in both the North Belton and the 'warp B' soils. Ferric oxide, a high proportion of which is often said to accompany good quality potatoes, is about the same in all the soils.

The Thornton Loch soil shows no chemical weakness, but its neighbour North Belton is very short of available potash and calcium carbonate, defects which could very well account for the inferior quality of potatoes raised from it. On the other hand, the 'warp A' soil, yielding the worst potatoes, gives a very good chemical analysis.

ANALYSIS OF TUBERS.

The 'specific gravity' was determined on about 1000 grams of medium sized tubers by weighing in air and again in distilled water. Dry matter and starch were determined in the air-dry meal after rapid drying of the sliced material at 55° C. Starch was estimated by a method described¹, depending on the action of a malt extract of predetermined 'diastatic activity' upon starch paste for a fixed time at constant temperature. The malt, kindly sent from the Guinness Laboratory had a 'conversion factor' of 82, *i.e.* by acting for 1 hour at 57° C. on a starch paste, 82 parts of maltose were formed for every 100 original parts of starch. The 'cupric reduction' of the resulting product was determined directly and calculated for maltose.

The results are given in Table III.

TABLE III.

| Origin of potatoes | Specific gravity | Dry matter per cent. | Starch per cent. | |
|----------------------|------------------|-------------------------|------------------|-----------------------|
| | | | in dry matter | in fresh substance |
| North Belton | 1.0844 | 23.31 | 81.6 | 19.02 |
| Thornton Loch | 1.0899 | 21.85 | 78.0 | 17.04 |
| Woburn | 1.0858 | 20.99 | 79.1 | 16.60 |
| Warp A, immature .. | 1.0750 | 18.93 | 68.0 | 12.87 |
| Warp A, mature | 1.0810 | 20.15 | 70.17 | 14.14 |
| Warp B | 1.0870 | 21.30 | 74.8 | 15.93 |

¹ *Trans. Guinness Laboratory*, Vol. I. No. 1.

The specific gravity, and dry matter, do not appear to show much relation to quality, although the three best lots stand near together. The low proportion of starch in the dry matter of potatoes from both 'warp' soils is worthy of note.

The nitrogen determinations were made on the fresh unsprouted material. A dozen average sized tubers were rasped down as fine as possible, well mixed, and portions withdrawn at once for the various estimations. The figures for the proteid nitrogen were obtained by adding the 'insoluble' nitrogen to that contained in the precipitate formed by boiling the filtrate for three minutes with a few drops of 5 per cent. acetic acid. The results are shown in Table IV. It will be observed that, on the whole, a low proportion of total nitrogen and a high proportion of non-proteid nitrogen accompany good quality. This is well shown by comparing the figures for the good quality potatoes from Thornton Loch and Woburn, with those for the two bad samples from 'warp A.'

TABLE IV.

Nitrogen determined in fresh tubers.

| | North Belton | Thornton Loch | Warp A, immature | Warp A, mature | Warp B | Woburn |
|---|-----------------|------------------|---------------------|-------------------|--------|--------|
| (a) Per cent. in dry matter | | | | | | |
| Total | 1.04 | 1.28 | 1.42 | 1.55 | 1.44 | 1.25 |
| Insoluble | 0.23 | 0.24 | 0.22 | 0.33 | 0.27 | 0.18 |
| Precipitated by acetic acid... | 0.25 | 0.26 | 0.52 | 0.62 | 0.33 | 0.33 |
| Proteid | 0.48 | 0.50 | 0.74 | 0.95 | 0.60 | 0.51 |
| Non-proteid | 0.56 | 0.78 | 0.68 | 0.60 | 0.84 | 0.74 |
| (b) Per cent. in fresh substance | | | | | | |
| Total | .237 | .270 | .270 | .315 | .301 | .261 |
| Proteid | .109 | .107 | .140 | .191 | .125 | .104 |
| Non-proteid | .128 | .163 | .130 | .124 | .176 | .157 |
| (c) Distribution of Nitrogen in parts per hundred of total Nitrogen | | | | | | |
| Insoluble | 21.94 | 18.88 | 15.19 | 21.58 | 18.27 | 14.18 |
| Acetic acid precipitate | 24.05 | 20.74 | 36.66 | 39.68 | 23.22 | 25.67 |
| Proteid | 45.99 | 39.62 | 51.85 | 61.26 | 41.49 | 39.85 |
| Non-proteid | 54.01 | 60.38 | 48.15 | 38.74 | 58.51 | 60.15 |

The results for the ash analyses are given in Table V.

The low amount of potash in the North Belton ash corresponds to a deficiency in the soil.

The high chlorine figures for the ash of the three bad samples stands in harmony with the often observed bad quality of potatoes manured with large dressings of chloride of potash or kainite.

TABLE V.

Ash of potatoes.

Pure ash—parts per hundred of dry matter.

Constituents—parts per hundred of pure ash.

| Origin | Pure ash | Potash | Phosphoric acid | Lime | Magnesia | Chlorine | Ferric oxide |
|--------------------|----------|--------|-----------------|------|----------|----------|--------------|
| North Belton | 3.28 | 53.84 | 11.60 | 1.28 | 3.25 | 6.42 | .43 |
| Thornton Loch ... | 3.97 | 56.32 | 9.70 | 1.04 | 3.52 | 2.57 | .25 |
| Warp A, immature | 5.36 | 56.35 | 10.86 | 1.05 | 3.37 | 6.15 | .43 |
| Warp A, mature ... | 4.65 | 57.24 | 10.74 | 1.16 | 2.77 | 4.47 | .49 |
| Warp B..... | 3.70 | 57.60 | 13.29 | 1.24 | 3.71 | 1.65 | .46 |
| Woburn | 4.31 | 58.61 | 14.80 | 1.48 | 2.61 | 2.97 | .20 |

POTATO SAMPLES OF THE SEASON 1904.

The season 1904 was in marked contrast to that of 1903. The latter with its cold wet summer and autumn was in every way abnormal, and disease was very widespread. The summer of 1904 was normal as regards rainfall and temperature, but owing to favourable vegetative conditions in late summer and autumn there was a good deal of 'second growth.'

Advantage was taken of the National Potato Society's variety trials at various centres, to secure samples of 'Up to Date' potatoes from seventeen localities.

The samples were subjected to a 'cooking test' of quality, the result of which, together with soil characteristics, is set out in Table VI. The samples are divided into three sets according to whether the 'blackening' was insignificant, moderate, or very marked. As in the 1903 samples discolouration was confined to the heel end of the tuber, and was most noticeable near the base.

TABLE VI.

Cooking test of potatoes from the crop of 1904.

| Locality | Behaviour | Soil |
|--------------------------------------|--|---|
| A. 'Blackening' insignificant | | |
| 1. Reading College | No blackening in any part | Sandy soil on red gravel |
| 2. Wallingford, Bucks. | Very slight darkening at heel end in individual tubers | |
| 3. Long Ashton, Somerst. | | |
| 4. Warwick | | Medium loam with gravel |
| 5. Chelmsford | | Heavy loam |
| B. Moderate 'blackening' | | |
| 6. Edmonton, Middlesex | | |
| 7. Cockle Park, Northumberland | | Medium loam on mixed clay and sandstone |
| 8. Wye College, Kent | | |
| 9. Merton, Surrey | | Sandy brash |
| 10. Orton, Wolverhampton | | Medium sandy loam |
| C. Marked 'blackening' | | |
| 11. Holmes Chapel, Cheshr. | Badly discoloured, especially those steamed in skins | Moderately heavy loam |
| 12. Halesowen, Stafford ... | " and diseased | Stiff loam on clay loam |
| 13. Droitwich | " and some diseased | Sandy loam on New Red Sandstone |
| 14. Evesham | " more diseased | Clay loam on loamy clay |
| 15. Kilnwick | " badly diseased | Marly loam on marl |
| 16. Creswell, Stoke | " " " | Medium loam on clay |
| 17. Bath | Shown blackening worse than any other | Clay loam manured in part with ashes |

EXPERIMENTS ON THE NATURE OF THE COLOURING MATTER.

It was observed that the freshly rasped material showed the same rapidity of surface change to red, brown and finally black, from both heel and seed halves of 'blackening' tubers and it was not less rapid from the best samples.

This excludes any connexion between 'blackening' and the action of the tyrosin splitting oxydase which causes the discolouration of the raw juice. That the discolouration is not due to physical causes was proved by drying and grinding a steamed piece of blackened tuber and comparing the hue of the powder with that from a similarly treated piece of normal colour. The powder from the blackened portion was grey in contrast with the creamy white of the other.

In the belief that the 'blackening' might be due to an oxidation of tannin derived from the splitting up of a glucoside during cooking,

| | Holmes Chapel, bad quality | | Evesham, bad quality | | Bath, bad quality | | Reading, good quality | | Cockle Park, good quality | | Warwick, good quality | |
|---|----------------------------|----------|----------------------|----------|-------------------|----------|-----------------------|----------|---------------------------|----------|-----------------------|----------|
| | heel end | seed end | heel end | seed end | heel end | seed end | heel end | seed end | heel end | seed end | heel end | seed end |
| Dry matter | 22.75 | 22.12 | 22.87 | 22.87 | 19.17 | 18.94 | 23.65 | 21.79 | 24.05 | 22.18 | 25.45 | 24.06 |
| Nitrogen in parts per hundred of fresh substance : | | | | | | | | | | | | |
| Total Nitrogen | 356 | 336 | 275 | 276 | 257 | 265 | 288 | 268 | 305 | 285 | 325 | 310 |
| Proteid Nitrogen | 162 | 168 | 132 | 135 | 120 | 122 | 113 | 119 | 130 | 119 | 135 | 134 |
| Non-proteid Nitrogen | 194 | 168 | 143 | 141 | 137 | 143 | 165 | 149 | 175 | 166 | 200 | 176 |
| Nitrogen in parts per hundred of dry matter : | | | | | | | | | | | | |
| Total Nitrogen | 1.565 | 1.519 | 1.152 | 1.160 | 1.341 | 1.399 | 1.196 | 1.230 | 1.263 | 1.285 | 1.316 | 1.288 |
| Proteid Nitrogen | .712 | .759 | .553 | .603 | .626 | .644 | .490 | .546 | .540 | .536 | .580 | .557 |
| Non-proteid Nitrogen | .853 | .760 | .599 | .557 | .715 | .755 | .697 | .684 | .723 | .749 | .786 | .731 |
| Proteid Nitrogen in parts per hundred of total Nitrogen | 45.5 | 50.0 | 48.0 | 49.0 | 46.7 | 46.2 | 41.8 | 44.4 | 42.6 | 41.9 | 40.3 | 43.2 |
| Non-proteid Nitrogen in parts per hundred of total Nitrogen | 54.5 | 50.0 | 52.0 | 51.1 | 53.3 | 53.8 | 58.2 | 55.6 | 57.4 | 58.1 | 59.7 | 56.8 |

Average distribution of nitrogen and dry matter in three bad and three good samples.

| | Holmes Chapel, Evesham, Bath, bad quality | | Reading, Cockle Park, Warwick, good quality | |
|---|---|----------|---|----------|
| | heel end | seed end | heel end | seed end |
| Dry matter | 21.93 | 21.14 | 24.38 | 22.68 |
| Nitrogen in parts per hundred of fresh substance : | | | | |
| Total Nitrogen | 206 | 202 | 308 | 288 |
| Proteid Nitrogen | 188 | 142 | 128 | 124 |
| Non-proteid Nitrogen | 153 | 150 | 180 | 164 |
| Nitrogen in parts per hundred of dry matter : | | | | |
| Total Nitrogen | 1.353 | 1.369 | 1.260 | 1.268 |
| Proteid Nitrogen | .630 | .609 | .523 | .546 |
| Non-proteid Nitrogen | .723 | .700 | .737 | .722 |
| Proteid Nitrogen in parts per hundred of total Nitrogen | 46.7 | 48.4 | 41.6 | 43.2 |
| Non-proteid Nitrogen in parts per hundred of total Nitrogen | 53.3 | 51.6 | 58.4 | 56.8 |

some determinations of tannin were made both on air-dry and fresh materials. The material was thoroughly extracted either with cold water or hot alcohol, and the tannin determined by the indigo-permanganate-hide powder method. The amount found varied from '04 to '05 per cent. of the dry matter, and showed no difference in heel and seed end of 'blackening' samples. As no sample hitherto examined has shown really strong discolouration, no further attempt could be made to separate a colouring matter present in such infinitesimal quantity.

NITROGEN DETERMINATIONS.

In order to observe whether 'blackening' stood in any relation to the distribution of nitrogen in heel and seed end, determinations were made on the transverse halves of tubers from six samples. Three samples (Reading, Cockle Park, and Warwick) which cooked well were compared with three (Holmes Chapel, Evesham, and Bath) which discoloured badly. The results are shown in Table VII.

The figures do not indicate that the distribution of nitrogen in the two ends of 'blackening' samples differs from the relation found in good cooking samples. The dry matter determinations show a consistently greater amount in the heel end over the seed end, indicating a higher proportion of starch near the base of the potato.

The proportion of nitrogen and the ratio of proteid to non-proteid is much the same as in the 1903 samples.

The good samples, as in 1903, show a lower total nitrogen in dry

TABLE VIII.

Average results for dry matter, and nitrogen in dry matter
for best and worst samples of two seasons.

| | Six bad samples: North Belton, Warp A immature, Warp A ma- ture, Holmes Chapel, Evesham, Bath | Six good samples: Thornton Loch, Woburn, Warp B, Reading College, Cockle Park, Warwick |
|--|---|---|
| Dry matter..... | 21.16 | 22.46 |
| Total Nitrogen | 1.348 | 1.293 |
| Proteid Nitrogen | .686 | .535 |
| Non-proteid Nitrogen | .662 | .758 |
| Proteid Nitrogen in parts per hundred of total Nitrogen | 50.9 | 41.4 |
| Non-proteid Nitrogen in parts per hundred of total Nitrogen | 49.1 | 58.6 |

matter and a higher proportion of non-proteid nitrogen as compared with the bad cookers.

In Table VIII. figures are given showing the average dry matter and nitrogen in dry matter for the good and bad samples of both years. These results show a higher dry matter and lower total nitrogen in the good quality potatoes, and in a very marked manner, high non-proteid nitrogen and correspondingly low proteid nitrogen.

CONCLUSIONS.

The high ratio of amide to proteid nitrogen in the good quality potatoes examined is a point of much interest, but will require to be confirmed by many more analyses before being regarded as a general characteristic of good quality tubers. The uniformly higher proportion of dry matter in the heel halves of all the samples indicates that the basal end of the tuber is richer in starch than the seed end, although this relation may not hold for material which has started to sprout.

Indications seem to point to physical causes as exercising the greatest influence on quality, especially such as determine temperature and water supply. The mechanical analyses of the soils, for instance, show that the best potatoes came from soils which were neither lacking in the coarse particles (gravel, grit, and coarse sand) which ensure porosity and consequently warmth, nor in the finest materials (fine silt and 'Klay') which secure retention of water.

Climate, as affecting the distribution of seasonal rainfall and air temperature, must always play an important part in modifying the value of a soil for raising good quality potatoes, so that although a light soil of good physical composition (*e.g.* Thornton Loch) produces the best quality tubers in a moist climate, a heavy soil may do better in a warm dry climate. It is proposed to continue the work along lines suggested by the foregoing considerations, making use of pot experiments with regulated conditions of temperature and water supply in soils of varying texture.

As previously mentioned no sample as yet examined has shown really strong 'blackening,' so that nothing conclusive as regards that aspect of quality has been arrived at.

The investigation is being carried out at the Laboratory of the Lawes Agricultural Trust, to whom my best thanks are due, for the use of the laboratory and apparatus. I must express my sense of deep obligation to Mr A. D. Hall, M.A., Director of the Rothamsted Experimental Station, who suggested the investigation, and continued to give me valuable advice throughout.

NOTE ON THE FATE OF CALCIUM CYANAMIDE IN THE SOIL.

By S. F. ASHBY, B.Sc.,

Carnegie Research Scholar, Rothamsted Experiment Station.

THE experiments described below have been carried out to confirm some results obtained by F. Löhns¹, who made it appear highly probable that soil bacteria were concerned in rendering calcium cyanamide assimilable for crops. It had been supposed that the reaction of calcium cyanamide in the soil was a purely chemical one². The material used was taken from a supply of "Kalkstickstoff" received at the Rothamsted Experimental Station from the "Cyanid Gesellschaft" of Berlin early this year. Nitrogen determinations by the Kjeldahl method showed the crude fertiliser to contain 20·3 per cent. nitrogen, equal to 58 per cent. pure calcium cyanamide. In order to obtain the action of soil organisms on the cyanamide a culture solution of the following composition was prepared:—

| | |
|---------------------------|-----------|
| "Kalkstickstoff" | 1·0 gram. |
| Monopotassium phosphate | 0·5 " |
| Cryst. magnesium sulphate | 1·0 " |
| Sodium chloride | 0·2 " |
| Dextrose | 1·0 " |
| Distilled water | 1 litre. |

Erlenmeyer flasks of 250 c.c. capacity each received 75 c.c. of the solution and 1 gram of fresh soil taken from arable land at a depth of 10 cm. Five of these were placed in the incubator without further treatment, two others were boiled for three minutes to secure sterilisation, and another pair to which no soil was added were treated with a few drops of a concentrated corrosive sublimate solution before incubation.

¹ *Centralbl. f. Bakt. Abt. II. Bd. 14, p. 87, 1905.*

² See this vol., p. 146.

Two control solutions not previously boiled gave by distillation with magnesia a mean of .70 mg. nitrogen, and another pair after boiling for three minutes yielded by distillation a mean of 1.2 mgs. nitrogen. The total nitrogen found by Kjeldahl's method was 15.0 mgs. in 75 c.c. solution and 1.4 mgs. in 1 gram of the soil. The flasks were incubated at 25° C. for 43 days, and were then examined for ammonia and total nitrogen. The two solutions inoculated with soil and boiled developed a surface film after a few days, and can consequently only be regarded as partially sterilised. The results of a qualitative examination are given in Table I.

TABLE I.

Incubation period at 25°: March 15—April 27, 43 days.
Iridescent surface film and deposit in all flasks seeded with soil.
Flasks containing corrosive sublimate showed no growth.
No solution showed either nitrite or nitrate.

| Culture | Ammonia by Nessler | Reaction |
|--------------------------|--------------------|------------------------|
| 1. Not boiled..... | abundant | strongly alkaline |
| 2. " | faint | weakly alkaline |
| 3. " | abundant | strongly alkaline |
| 4. " | moderate | less strongly alkaline |
| 5. " | faint | moderately alkaline |
| 6. Partly sterilised ... | " | weakly alkaline |
| 7. " | " | " neutral " |
| 8. Corrosive sublimate | none | " |
| 9. " " | " | " |

The results of the determinations of ammonia by distillation with magnesia and of the nitrogen in the residue therefrom by Kjeldahl's method are shown in Table II.

Culture (5) was not distilled but was tested for sugar with Fehling's solution, and gave a negative result. It is evident that the alkalinity of all the incubated solutions was due to free ammonia, so that it is not surprising that a considerable loss of nitrogen by volatilisation took place. In the solutions to which corrosive sublimate had been added there was practically no formation of ammonia, indicating that a sterile calcium cyanamide solution can be kept for a long time without any notable reaction occurring with the water present. It is reasonable to infer from this, that the formation of ammonia from cyanamide in the soil can be due in only a very minor degree to a purely chemical process. On the other hand where soil organisms were active as much as 80 per cent. of cyanamide nitrogen was converted to ammonia.

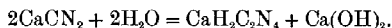
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TABLE II.

| Solution | Nitrogen Magnesia distillation | Nitrogen Magnesia residue | Nitrogen, total found | Nitrogen originally present | Nitrogen lost by evaporation | Nitrogen changed to Ammonia | Nitrogen parts per hundred of original, changed to Ammonia |
|---|--------------------------------|---------------------------|-----------------------|-----------------------------|------------------------------|-----------------------------|--|
| 1. Not boiled..... | mgs. 7.40 | mgs. 4.19 | mgs. 11.59 | mgs. {15.0 + 1.4} (soil) | mgs. 4.81 | mgs. {12.21 - .70} = 11.51 | per cent. 80.5 |
| 2. „ | 1.82 | lost | — | 16.4 | — | — | — |
| 3. „ | 7.26 | 5.59 | 12.85 | 16.4 | 3.55 | 10.11 | 70.7 |
| 4. „ | 4.47 | 10.06 | 14.53 | 16.4 | 1.87 | 5.64 | 40.0 |
| 6. Boiled, partly sterilised.... | 8.35 | 9.22 | 12.57 | 16.4 | 3.88 | {7.18 - 1.2} = 5.98 | 39.9 |
| 7. „ ... | 2.65 | 11.60 | 14.25 | 16.4 | 2.15 | 3.60 | 24.0 |
| 8. Corrosive sub- limate sterilised) | 0.70 | 13.97 | 14.67 | 15.0 | 0.33 | 0.33 | 2.2 |
| 9. „ ... | 0.70 | 14.04 | 14.74 | 15.0 | 0.26 | 0.26 | 1.7 |

Löhnis in a further communication¹ has shown that two organisms (B. Kirchneri and B. lipsiense), isolated by him from cyanamide solutions seeded with soil, can ammonify that fertiliser very rapidly. They act very feebly on urea and peptone, while the bacteria which rapidly ammonify urea and peptone show little or no power to attack calcium cyanamide.

It may be remarked in conclusion that calcium cyanamide CaCN_2 , contained in "Kalkstickstoff" is insoluble in water but reacts with the latter to form a soluble salt and calcium hydrate which renders the freshly prepared solution alkaline:



The author was able, by precipitating all the lime with ammonium oxalate, evaporating the filtrate to dryness, extracting with a little strong alcohol and allowing the latter to evaporate at the ordinary temperature, to obtain yellow crystalline plates which yielded on analysis 62.70 per cent. nitrogen and agreed with the description given for dicyandiamide (Beilstein, *Organische Chemie*) which contains when quite pure 66.60 per cent. nitrogen. A solution of calcium cyanamide after long standing goes over into dicyandiamide which yields no ammonia by distillation with magnesia.

¹ *Centralbl. f. Bakt.* II. 14, p. 389.

THE BEARING OF MENDELISM ON THE SUSCEPTIBILITY OF WHEAT TO RUST.

By E. J. BUTLER, M.B., F.L.S.,

Cryptogamic Botanist to the Government of India.

IN Mr Biffen's paper on "Mendel's Laws of Inheritance and Wheat Breeding" in the first number of this *Journal* reference is made on page 40 to the characters of immunity and susceptibility to the attacks of yellow rust. Mr Biffen's experiments confirm the conclusions of other observers, such as Farrer in Australia, that resistance and susceptibility to rust are inherited characters, and he shows that they follow the Mendelian laws. As the question is of enormous practical importance in the wheat growing countries this general statement requires to be made more precise. It holds for a given rust in a particular locality; it may or may not hold where the wheat is exposed to the attacks of a second species of rust or when it is transferred to another locality. Thus experience in India so far seems to show that resistance to yellow rust, *Puccinia glumarum*, does not imply resistance to orange rust, *P. triticea*. And it is certain that the characters alter with change of locality. Several of Farrer's hybrids resistant to Australian rusts have proved susceptible to the same rusts in India. On the other hand *Kathia* wheat, which is particularly liable to the attacks of all three Indian wheat rusts, has been recommended by Carleton for extended trial in the United States, having shown a promising degree of resistance to yellow rust there. A still more striking case is that of spelt wheat, which has proved very resistant in some parts of India and not in others. Therefore in the breeding of rust-resistant wheats the results of work in one locality should be accepted with caution in others as long as we do not know on what immunity depends. In spite of this it is impossible to exaggerate the practical value, for countries like India, where the extension of wheat cultivation is largely bound up

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with the production of wheats possessing certain definite characters, such as resistance to rust, drought, &c., of the work already done in defining the lines on which wheat breeding must proceed in the future.

In the same section of his paper Mr Biffen concludes that his results are opposed to the assumption of a latent germ in the wheat grain, through which the disease is transmitted from season to season. For he found that the progeny of a cross were equally susceptible whether the male or female parent was the susceptible one, although the latent germ must necessarily arise from the female only. Though Eriksson's "mycoplasma" hypothesis requires establishment on a more solid basis than has been the case so far, still it is difficult to see how the results mentioned vitiate it. Were it the case that immunity depends on the absence of the latent germ from the grain, then Mr Biffen would probably be right. But there is an immunity dependent on the behaviour of the tissues of the leaf to infection by spores which should not be lost sight of. Mr Massce¹ and Mr Salmon² have shown how the resistance of a leaf may be overcome by appropriate chemical or physical treatment, and Professor Marshall Ward³ that resistance to yellow rust is due to the reaction between the uredospores and the leaf-cells, and has nothing to do with the character of the grain. That susceptibility to rust means this liability to uredospore infection, and not a large proportion of germ-bearing grains is shown by the following experiment. A tent of thin cloth, more or less impervious to air-borne spores, 19 x 10 ft., was erected on one of my wheat plots at Dehra Dun on December 18th, 1904. Yellow rust was first observed in the field on January 1st, 1905. The tent was opened on February 11th, by which time a good deal of rust had developed on the surrounding wheat. The rusted leaves within the tent were counted, and 160 leaves bearing uredo sori collected within 1½ feet of the margin while the remainder of the area enclosed by the tent gave 24 only. So that in the marginal 78 square feet 160 leaves bore rust, while the central 112 square feet had only 24. Were the rusting of this wheat—a moderately susceptible one—due to a large number of latent germs in the grain, there is no explanation of this difference. As a matter of fact it was clear that the rusting of the margin was due to the entrance of aphides and other insects, carrying uredospores, at the ground level where the tent cloth was fastened down by stones only, and considerable numbers of these

¹ *Phil. Trans.* Vol. cxcvii. 1904.

² *Annals of Botany*, Vol. xix. No. lxxiii. p. 125, 1905.

³ *Ibid.* p. 89.

insects were found near the edge. They were fewer towards the centre, and secondary infection of the central part from the rust near the margin had not occurred to any great extent both from the shortness of time which had elapsed before the tent was opened and from the stillness of the air inside. We are therefore, I think, justified in concluding that susceptibility to rust depends on the liability of the leaves to uredospore attack, and that the latent germ, if it exist at all, can only do so in a comparatively small proportion of grains. No wheat is as yet known on which rust may not sometimes appear, so that immune sorts may bear the latent germ for all we know as often as the susceptible. And it also follows that experiments to test the existence of the germ by growing wheat in spore-tight cases, where only a few plants can be grown, are not likely to give positive results except accidentally, whether the hypothesis be true or not. Finally, if the presence or absence of the germ be independent of the susceptibility or immunity of the wheat to rust, then the behaviour of wheat in regard to Mendel's laws can have no bearing on the "mycoplasma" hypothesis.

NOTE ON THE INHERITANCE OF HORNS AND FACE COLOUR IN SHEEP.

By T. B. WOOD, M.A.,

Secretary Cambridge University Department of Agriculture.

THE following short note gives the preliminary results of an experiment which I have commenced on a small scale on my father's farm at Field Dalling, near Holt, in Norfolk.

The object of the experiment is to follow out the inheritance of various characters in sheep. In the autumn of 1903 my father placed at my disposal 30 of his Suffolk ewes. Suffolk sheep of both sexes are characterised by black faces and the absence of horns. I determined to cross them with a Dorset ram, Dorsets having in both sexes white faces and large horns. For the present, characters other than horns and face-colour are neglected.

From the 30 Suffolk ewes mated in the autumn of 1903 with a Dorset ram 43 lambs were born in the spring of 1904. Of these 25 were males and, unfortunately for the continuance of the experiment, only 16 females. All the latter were kept for breeding. Two rams were kept, the remaining 23 males being castrated and fattened during the winter of 1904-5.

In the autumn of 1904 the 16 cross-bred ewe lambs were mated with one of their half-brothers. Both the ram and the ewes were rather young to breed from, and the crop of lambs was small. Six of the ewes were barren, one aborted, one gave birth to two dead lambs, one produced a lamb which died immediately after birth. The remaining seven produced eight lambs, which were all reared.

The parents and both generations of offspring are illustrated in the accompanying plate. They are described below, so far as they vary in horns and in colour of face and legs. The numbers refer to those on the plate.

Parents.

1. Dorset Ram. Horns, white face and legs.
2. Suffolk Ewe. No horns, black face and legs.
3. Dorset Ewe. Horns, white face and legs.

First generation. Dorset Ram \times Suffolk Ewes.

5. Ram. Horns, speckled face and legs. The second ram was



1. Dorset Ram.



2. Suffolk Ewe.
Parental Types.



3. Dorset Ewe.



4. Ewe.



5. Ram.
First Generation.



6. Ewe.



7. Ram.



8. Ewe.
Second Generation.



9. Ram.



10. Ram.



11. Ram.
Second Generation.



12. Ewe.

drowned when 3 months old. At this age both the rams had large horns of about the same size, and far larger than those that had been castrated.

4 & 6. Ewes. No horns, speckled face and legs.

Second generation. First cross ram first cross ewes.

10. Ram. Horns, white face and legs. There were two lambs of this type.

9. Ram. No horns, white face and legs.

7. Ram. Small horns, face white, with black rings round eyes; legs white, slightly speckled with black. There were two lambs, twins, of this type.

11. Ram. Small horns, speckled face and legs.

8. Ewe. No horns, speckled face and legs.

12. Ewe. Horns, face black, but with what appears to be rather wool than white hair on cheeks and forehead.

The Dorset ram used in 1904 was bought as pure bred from a Dorset breeder. The Suffolk ewes were not registered animals, but I have known the strain for some years, and have never seen either a horn produced or any white hair on face or legs. They may therefore be taken as pure in these characters.

It will be seen from the plate that the first generation hybrids have speckled faces and legs, and that in the second generation white faces, black faces, and speckled faces are produced: also that the first generation hybrid ewes have no horns, whilst the rams grow large horns. If, however, the rams are castrated the growth of their horns ceases. This accounts for the smallness of the horns in numbers 7 and 11 in the plate. In the second generation both horned and hornless animals of both sexes were produced.

A number of Dorset ewes were mated with a Suffolk ram at the University Farm in the autumn of 1904 in order to breed a number of cross-bred sheep reciprocal to the crosses bred at Dalling. The face-colour is again the same and the males are horned, the females hornless.

It would appear, therefore, that when black and white faced sheep are crossed the hybrids have speckled faces, and that these hybrids do not breed true *inter se*, but split into white faces, black faces, and speckled faces.

As regards horns, it appears that when Dorset sheep having horns in both sexes are crossed with hornless Suffolk sheep, the male offspring have horns, the females do not; or in other words, horns are dominant in males, recessive in females.

NOTE ON
"BERICHT ÜBER DIE ARBEITEN DER INTERNATIONALEN
KOMMISSION FÜR DIE ANALYSE DER KUNSTDÜNGER
UND FUTTERMITTEL DES V. INTERNATIONALEN KON-
GRESSES FÜR ANGEWANDTE CHEMIE ZU BERLIN, 1903."

By T. B. WOOD, M.A.

At the beginning of October, 1904, many agricultural chemists in England received copies of the above publication from the Secretary of the commission, Dr M. Ullmann, of Hamburg, together with a letter asking all who were willing to agree with the recommendations printed in the report to signify their assent to him. Copies of the report were circulated to members of the Chemical Committee of the Agricultural Education Association, and the recommendations were informally discussed at a meeting of the committee on Dec. 8th. It was suggested that a note should be published in order to call the attention of agricultural chemists to the subject, and facilitate further discussion.

The history of the matter is briefly as follows:—At the first International Congress of Applied Chemistry held at Brussels in 1894 the subject was brought forward, and was again discussed at the Paris Congress in 1896. At the Vienna Congress in 1898 a committee was appointed to investigate the methods of analysis used for manures and feeding stuffs in various countries, and to draw up a series of recommendations with a view to securing international uniformity of method. This committee presented an incomplete report at the Paris Congress in 1900, and its powers were prolonged in order that the final report might be presented at the Berlin Congress in 1903.

This was done, and the report and recommendations were presented and unanimously accepted.

The English translation of the recommendations is printed below:—

METHODS FOR THE ANALYSIS OF ARTIFICIAL MANURES
AND FEEDING STUFFS ADOPTED AT THE GENERAL
MEETING AT BERLIN ON JUNE 3, 1903, OF THE FIFTH
INTERNATIONAL CONGRESS OF APPLIED CHEMISTRY.

The following publications are cited as references :

Die landwirtschaftlichen Versuchstationen, Berlin, Paul Parey,
for artificial manures Bd. 38, 41, 43, 51, 52,
for feeding stuffs ... Bd. 36, 37, 38, 45, 49, 51.

Methoden zur Untersuchung der Kunstdüngemittel, 3. Aufl., Berlin, 1903,
Weidemannsche Buchhandlung, herausgegeben vom Verein Deutscher
Dünger-Fabrikanten.

U. S. Dept. of Agric. Div. of Chem., Washington, Bull. 46, 65, 81.

König, *die Untersuchung landw. und gewerbl. wichtiger Stoffe*, Berlin,
1898, Paul Parey.

Wiley, *Principles and Practice of Agricultural Analysis*, Vol. II.
and III.

Sidersky, D., *Analyse des engrais*, Paris, 1901, Béranger.

Petermann, A., *Méthodes suivies dans l'analyse des matières fertilisantes*,
Gembloux, 1901.

INTERNATIONAL REGULATIONS FOR SAMPLING WHOLESALE QUANTITIES
OF RAW MATERIALS AND PRODUCTS OF THE FERTILISER INDUSTRY.

1. Samples not drawn in accordance with these regulations are to be refused by the official analysts, such refusal being recorded on the certificate.

2. Samples are only to be considered as properly taken, if drawn during unloading on railway or quay, in the presence of representatives of both parties, or by a sworn sampler, and in accordance with these regulations.

3. In the case of manufactured products, a sample is to be taken by means of a sampling iron from every tenth bag, or if the material is in bulk, from at least ten different places throughout the parcel.

4. In the case of shiploads of raw materials every 50th bag or bucketful during discharge (corresponding to 2% of the whole) is to be set aside, and from this, after first crushing to at least the size of a hazel-nut, a sample is to be taken for the determination of moisture;

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a further sample for the determination of the constituents of value is to be taken in the same way as in the case of manufactured products, after the sample has been reduced to a fine state by grinding and sifting.

5. The samples—in weight about 300 grams—are to be filled loosely into strong, clean and absolutely dry glass bottles.

6. At least three samples are to be taken. The bottles are to be hermetically closed and sealed by the persons conducting the sampling.

7. The labels are to be signed by the persons taking the sample and are to be attached by means of the wax used in sealing the bottles.

8. The samples are to be kept in a cool, dark, and dry place.

9. Materials of heterogeneous composition must be sufficiently reduced in size and mixed before bottling.

PREPARATION OF SAMPLES.

(a) Dry samples of phosphates or other artificial manures may be simply sifted and then mixed.

(b) In the case of damp materials, where the above procedure is not possible, the preparation must be confined to a careful mixing by hand.

(c) In the case of raw phosphates and animal charcoal, a water determination is to be made, as confirmatory evidence.

(d) In dealing with substances which are apt to lose water during grinding, the moisture is to be determined both before and after the preparation of the sample, the results of the analysis being afterwards calculated back into the original hygroscopic condition of the sample as received.

METHODS OF ANALYSIS.

A. Artificial Fertilisers.

I. DETERMINATION OF MOISTURE.

Ten grams of the substance are used; the drying is conducted at 100° C. to constant weight; substances containing gypsum are dried three hours.

For potash salts the regulations of the Kalisyndicat at Leopoldshall-Stassfurt hold good.

II. DETERMINATION OF INSOLUBLE MATTER.

Ten grams of the substance are used.

A. When the substance is dissolved in mineral acids, the silica is rendered insoluble and the total residue ignited.

B. When the substance is dissolved in water, the residue is dried at 100° C. to constant weight.

III. DETERMINATION OF PHOSPHORIC ACID.

A. *Method of making the Solutions.*

1. In the case of water-soluble P_2O_5 twenty grams of the substance are to be agitated for 30 minutes with about 800 c.cm. water in a litre bottle and then filled up to 1000 c.cm. The solution of so-called double superphosphates must be boiled with HNO_3 previous to precipitation of the P_2O_5 , whereby any pyrophosphoric acid, which may be present, is converted into orthophosphoric acid.

For every 25 c.cm. of solution of double superphosphate 10 c.cm. concentrated HNO_3 must be taken.

N.B. When the amount of citrate-soluble phosphoric acid in superphosphates is required, the determination must be made according to Petermann's method.

2. For total phosphoric acid 5 grams of the substance are boiled with aqua regia or 20 c.cm. HNO_3 and 50 gms. concentrated H_2SO_4 for 30 minutes and made up to 500 c.cm.

3. P_2O_5 in Basic slag¹.

(a) Citric-soluble P_2O_5 .

Five grams of the substance are placed in a 500 c.cm. flask with 5 c.cm. of alcohol to prevent caking and shaken with 2% citric acid solution for one half-hour at 17°5 C. in a rotary apparatus which makes 30–40 revolutions per minute.

(b) Total P_2O_5 .

Ten grams of the substance are placed in a 500 c.cm. flask, thoroughly mixed with a few c.cm. of water and boiled for 30 minutes with 50 c.cm. concentrated H_2SO_4 , the flask being frequently shaken.

¹ Basic slag, which appears to contain coarse particles, is passed through a 2 mm. sieve; the portion, which remains behind, is slightly crushed. The determination of P_2O_5 is made in the portion which passes through the sieve, the result being calculated so as to include the portion which remains behind.

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B. *Analysis of the Solutions.*

1. Molybdate-method according to Fresenius and P. Wagner.
2. Citrate method.
3. Free acid.

- (a) Total of free acid: The aqueous solution A 1 is titrated with a solution of NaOH, using methyl orange as an indicator, or
- (b) Free phosphoric acid: An alcoholic solution is used for making a gravimetric determination.

IV. DETERMINATION OF FERRIC OXIDE AND ALUMINA.

This determination must be made either according to the method of Eugen Glaser¹ as improved by R. Jones², or, in the case of the determination of alumina, according to Henri Lasne³. The method adopted must be mentioned.

V. DETERMINATION OF NITROGEN.

1. *Nitric Nitrogen.*

Only direct methods must be used.

- (a) Reduction methods according to Böttcher⁴, Ulsch, Devarda and Kjeldahl-Jodlbauer.
- (b) Gasometric methods. Lunge, Schloesing-Grandeau.

2. *Nitrogen present as Ammonia.*

The determination must be made by distillation with magnesia. With ammonia-superphosphates the solution given under III. A. 1 must be used.

3. *Total Nitrogen.*

In presence of nitrates this determination must be made according to Kjeldahl-Jodlbauer.

4. *Organic Nitrogen.*

In the absence of nitrates and ammonia the determination must be made according to Kjeldahl or by combustion with soda lime.

¹ Glaser, *Zeitschr. f. angew. Chemie*, 1889, S. 636, s. a. *Landw. Vers.-Stat.*, Bd. 38, S. 284.

² R. Jones, *Zeitschr. f. angew. Chemie*, 1891, S. 3, s. a. *Fresenius Zeitschr.*, 30, S. 743.

³ Lasne, *Bull. Soc. Chim.*, T. 15, S. 146 u. 237, s. a. *Chem. Ztg.*, Repert. 1896, S. 47 u. 65.

⁴ Early method of Kühn, *Landw. Vers.-Stat.*, Bd. 41, S. 165 u. 379.

VI. DETERMINATION OF POTASH.

This determination must always be made with platinum chloride or with perchloric acid. The method adopted must be specified.

VII. DETERMINATION OF LIME AND MAGNESIA.

In lime used as a fertiliser and in chalky clay this determination can be made either according to the titration method of Tacke or by the usual gravimetric method. The method adopted must be mentioned.

B. Feeding Stuffs.

Preparation of samples.

Samples of all feeding stuffs must be passed through a 1 mm. sieve, if possible.

I. DETERMINATION OF MOISTURE.

Five grams of the substance are dried for three hours at 100° C.
As regards linseed cake see III. 1.

II. DETERMINATION OF PROTEIN¹.1. *Determination of Crude Protein.*

1—5 grams of the substance are taken. The nitrogen determination is made according to Kjeldahl or Gunning-Atterberg and the amount of nitrogen found is multiplied by 6.25. In the case of feeding stuffs which are difficult to dissolve, such as cotton-seed meal, peanut meal, etc. an addition of phosphoric anhydride is recommended.

2. *Determination of Albuminoid Nitrogen.*

The determination is made according to Stutzer or Kellner. The method employed must be specified.

3. *Determination of the Digestible Protein.*

Stutzer's method improved by G. Kühn is to be used. Instead of gastric juice commercial pepsin can be employed, with restrictions according to Wedemeyer.

¹ In feeding stuffs, where the carbohydrates have an accepted nutritive value, the determination of the value of the nutritive constituents from a commercial standpoint is made on the basis of the ratio 3 : 3 : 1 for Protein : Fat : Carbohydrates. (*VII Hauptversammlung des Verbandes landwirtschaftlicher Versuchstationen im Deutschen Reiche*, Kiel, 1895.)

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III. DETERMINATION OF THE FAT.

1. Feeding stuffs must be dried for three hours at 95° and in no case above 100°. In the case of linseed cake and other cake containing drying oils this can be done in an atmosphere of hydrogen or coal gas or only one hour at 100°. The ether used for the extraction must contain neither alcohol nor water. The extraction must be a complete one. The dried extract need not be soluble in ether.

2. Molasses feeds. 25 grams of substance are to be dried for three hours at 80° C. and ground when cool. Five grams of the powder must be washed out in a Gooch crucible with about 100 c.cm. cold water, added drop by drop. The residue to be dried at 95° and extracted by ether.

IV. DETERMINATION OF NITROGEN-FREE EXTRACT.

(a) This is usually obtained by difference after all the other constituents have been determined.

(b) For the determination of sugar the regulations of the International Sugar Commission hold good.

V. DETERMINATION OF CRUDE FIBRE.

According to Weende's method, three grams of substance, from which the fat (if present) has been extracted, are boiled with 200 c.cm. H_2SO_4 of 1.25% and 200 c.cm. of potassium hydrate solution of 1.25%. Each boiling must last $\frac{1}{2}$ hour, water being added to replace the evaporated portion. Each treatment with acid or alkali must be followed by a boiling with water. The residue to be washed with hot alcohol, then with ether, and dried to a constant weight. The ash of the residue must be subtracted.

VI. DETERMINATIONS OF THE ASH.

Five grams of the substance are incinerated and the residue is carefully weighed.

VII. DETERMINATION OF THE SAND OR MINERAL INGREDIENTS.

The examination of all feeding stuffs for sand or mineral admixtures is obligatory. When the preliminary examination shows the presence of more than normal amounts a quantitative determination must be made. The result to be communicated to the remitter of the sample when the preliminary examination is ratified, at all events in all cases where the contents show more than 1%.

The acceptance of these methods for the analysis of artificial manures and feeding stuffs at the general meeting of sections I and VII on Thursday, June 4, 1903, and at the general meeting of the Congress on

Monday, June 8, 1903, constitutes a second reading, the first reading having taken place at Paris in 1900.

As will be seen the labours of the International Commission deputed by the Berlin Congress to deal with the subject of the analysis of artificial manures and feeding stuffs have resulted in a definite agreement being arrived at.

Leaving out the sections on the sampling of wholesale quantities of raw materials, and preparation of samples, the rest of the recommendations may be divided into two, those that aim at establishing uniform conventional methods (for instance A. III. 1, defining water-soluble P_2O_5 , and B. V. defining crude fibre), and those that attempt to dictate which particular one of many absolute methods shall be used (for instance A. V. 1, 2, 3, 4). With regard to the former it is no doubt desirable for many reasons that there should be a wide agreement on purely conventional methods, but the need of uniformity in the latter class is by no means apparent. It would certainly be for the general good if all analysts would agree for instance to determine fibre in the same way, for the result must vary with details of method, but no useful purpose would be served by all analysts using exactly the same method of estimating nitrogen, for the percentage of nitrogen in a substance is a fact which admits of accurate determination in more than one way.

At a meeting of the Agricultural Education Association it was decided to give the recommendations which define conventions (indicated by larger print in the accompanying text) careful consideration, as it is eminently desirable that English chemists should as far as possible fall into line.

VARIATION IN THE CHEMICAL COMPOSITION OF THE SWEDE.

ON page 258 Mr A. D. Hall has made some criticisms on the figures contained in my paper, named above.

The first part of his remarks, dealing with the comparative magnitude of errors and factors, would apply to any investigation. Providing any such investigation were fairly extensive, there should be cases where a "factor" would approach zero (see page 105), compared with which any small error must approach infinity.

As I pointed out on page 100, the extreme seasonal variation is 4.64 per cent., and on page 98 the extreme variation due to the farm is 1.95 per cent., and to the variety 1.85 per cent., compared with which the difference between duplicates (.38 per cent.) is small. By averaging many results the error becomes smaller.

Mr Hall then writes, "Mr Collins's argument would be more convincing if he could give us some idea of the degree of accuracy to be expected in his various 'factors.'" This has already been done in Table X (page 103 *et seq.*) and in Table VII (page 99). There is no Waterloo swede in my paper; but assuming that this is a misprint for Kangaroo, the following comparison of variety factors results:—

(a). Holborn Elephant. Mr Hall's calculation, Maximum + .265, Minimum + .055; my calculation (page 103), + .26 and + .08 respectively. There is no essential difference between Mr Hall's calculation and mine, except that in using two places of decimals I could plead convention, whereas Mr Hall's use of three places of decimals is hard to justify.

(b) Holborn Kangaroo. Mr Hall's figures, $\frac{1}{2}$.32 and + .08; my figures (page 103), + .31 and + .09. Again no essential difference.

Mr Hall then refers to "Eshott in 1903" and immediately after to "Eshott in 1902." I imagine that here is a second misprint, but

as I cannot guess which year is correct, I must leave the matter alone.

Mr Hall then asks me to review my results "from the point of view of the relative magnitude of the 'factors' and of the probable errors involved in their determination." Mr Hall's own calculations show that this error is about ± 1 per cent., and in my paper (page 103 *et seq.*) I have shown the errors to be of about the same magnitude ($\pm .03$ to $\pm .12$). In my conclusion I state, "These analyses and calculations now enable us to draw up a list of varieties in order of merit (see Table VIII)." Anyone looking at Table VIII will see that I have struck out the second decimal place, which is much the same thing as stating that the errors are about ± 1 . Hence Mr Hall's final request has already been carried out for all essential purposes.

S. H. COLLINS.